A TECHNICAL JOURNAL FOR DESIGNERS AND USERS OF ELECTRICAL, ELECTRONIC, HYDRAULIC, MECHANICAL AND PNEUMATIC CONTROL SYSTEMS AND INSTRUMENTATION

CONTROL

SYSTEMS • INSTRUMENTATION • DATA PROCESSING • ENGINEERING • APPLICATIONS

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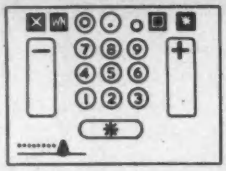

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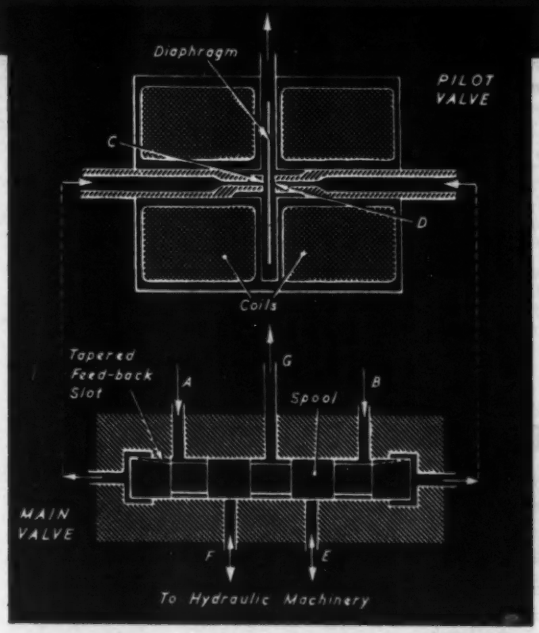

The valve — see diagram — consists of a main valve and a pilot valve. The main valve is supplied with pressure oil through ports A and B. When the spool is in the central position — as shown — the oil escapes through the tapered slots to the opposed jets C and D in the pilot valve and impinges on each side of the diaphragm. The two coils can be energised to attract the diaphragm towards one or other of the jets. If the signal to the right hand coil is the stronger, the diaphragm will flex to the right, restricting the flow from the right hand jet and thus increasing the pressure in that line. Similarly, the pressure in the left hand line is reduced. This pressure difference is transmitted to the main valve and causes the spool to move to the left until the resultant decrease in discharge area of the tapered slot at the right hand end of the spool and the increase in that at the left cause equilibrium to be restored. The displacement of the spool uncovers ports E and F, thus opening pressure and return lines to the hydraulic machinery.

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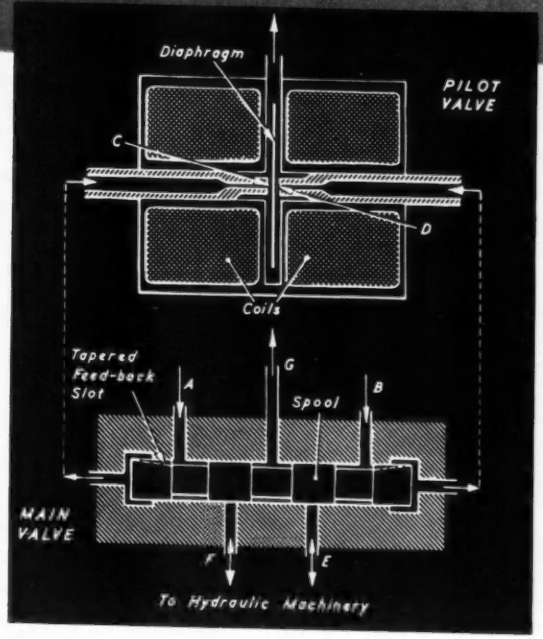

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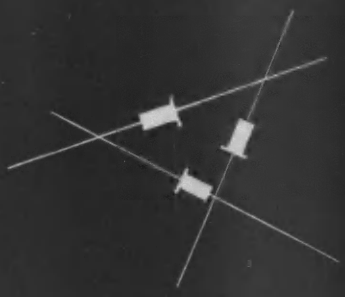

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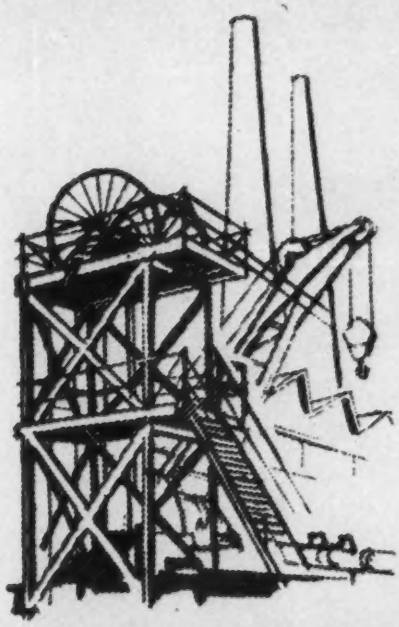

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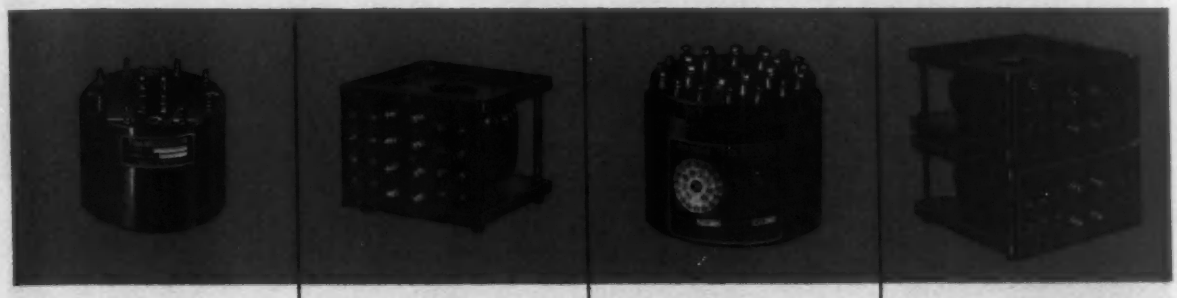

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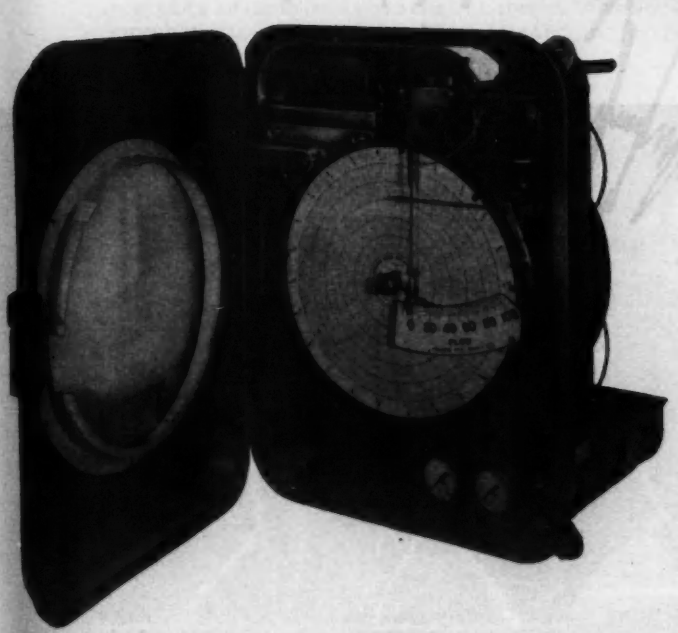

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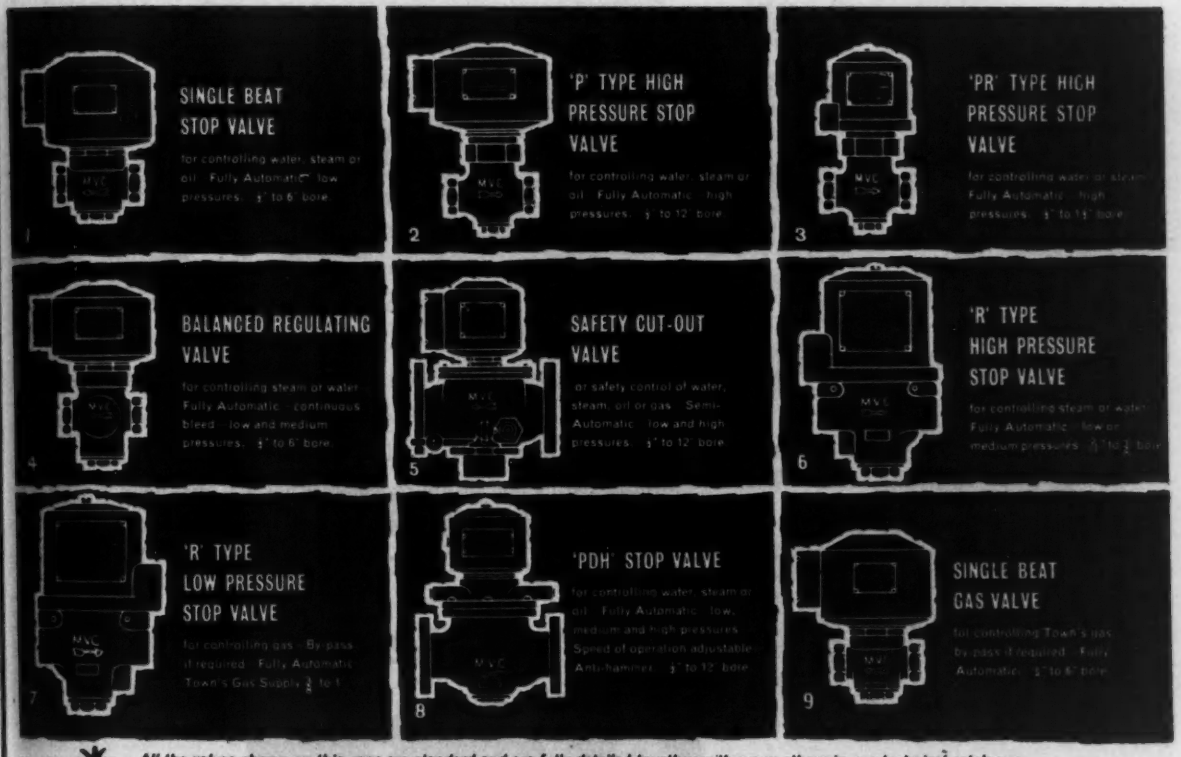
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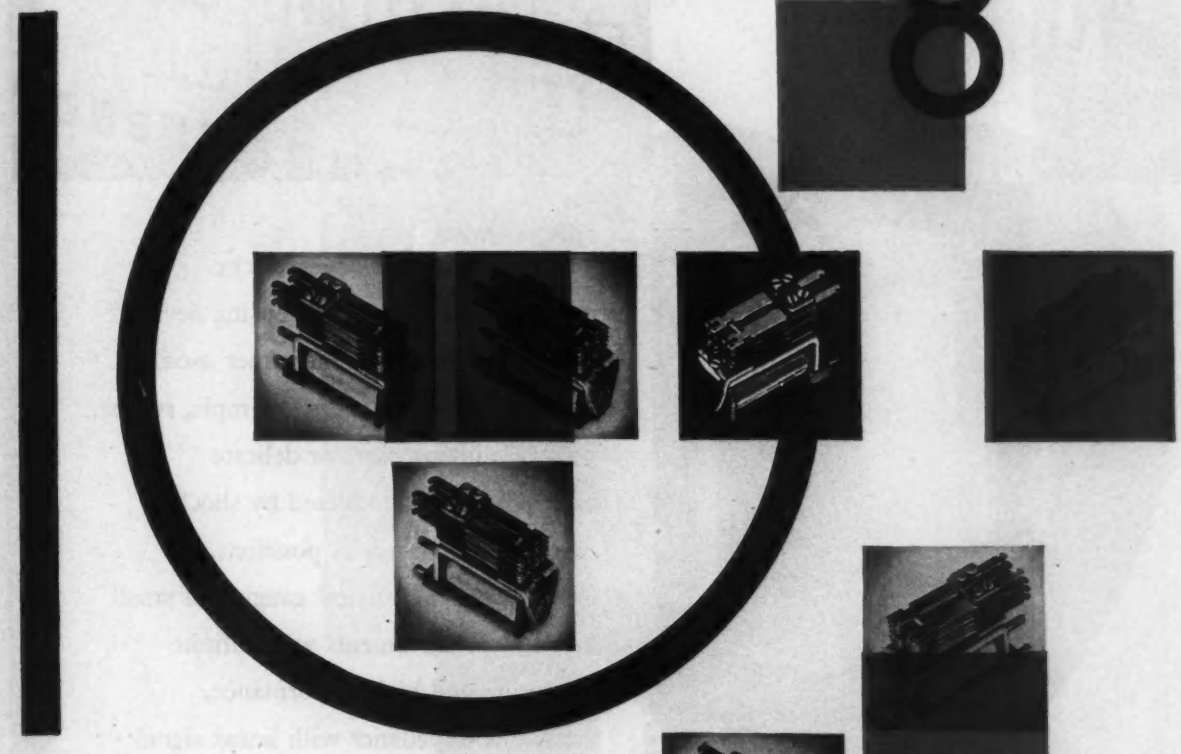

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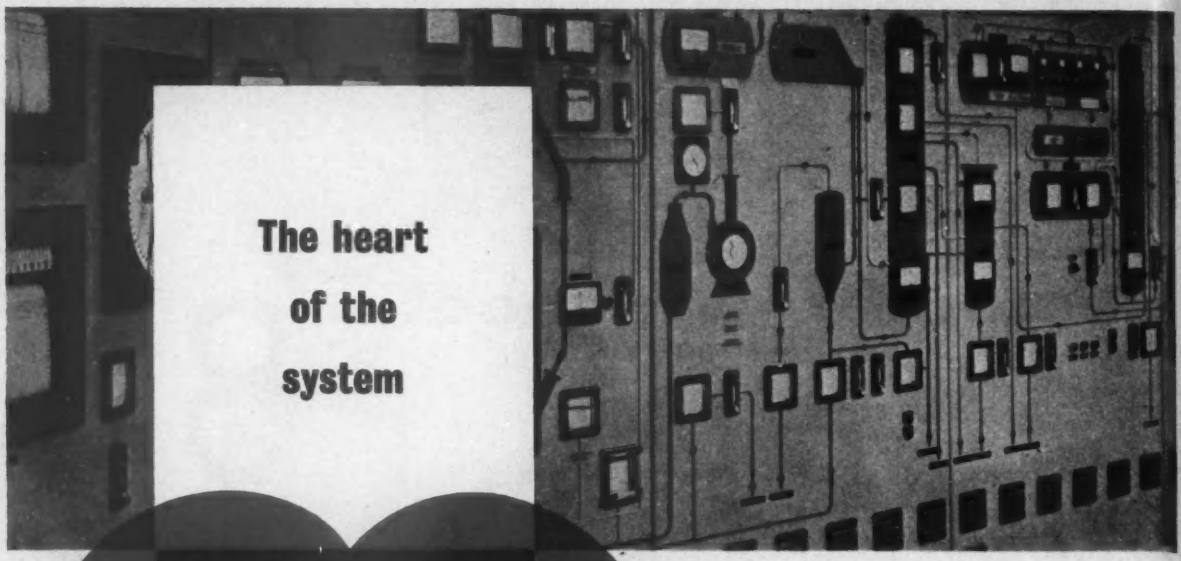
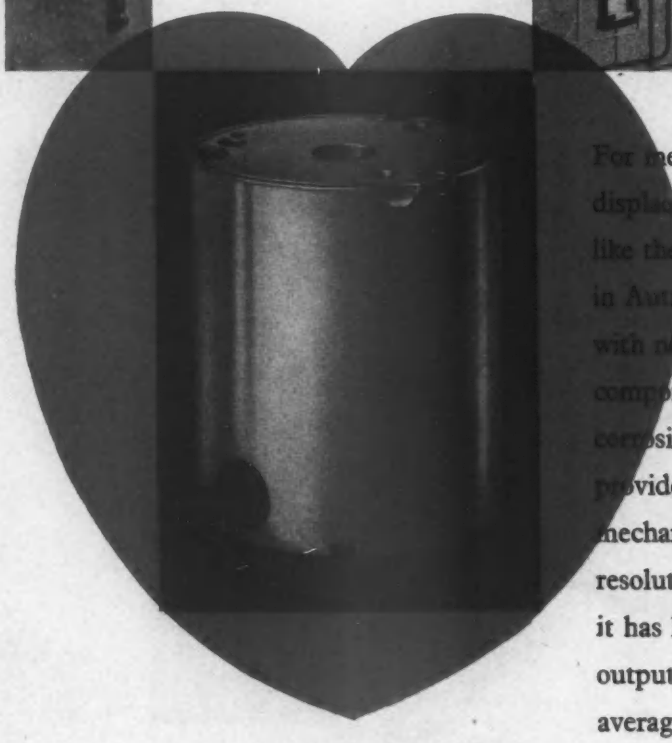


The heart of the system



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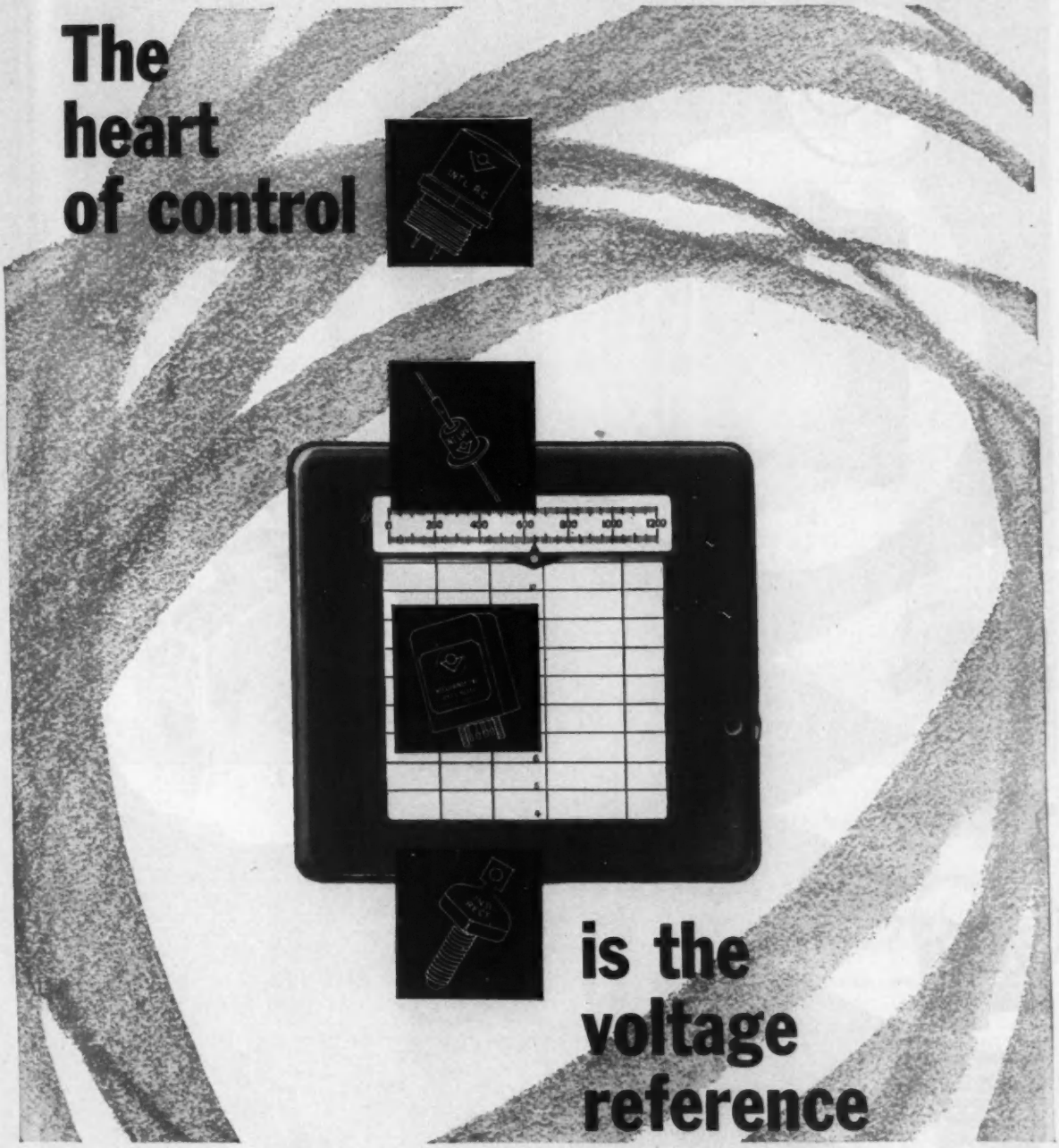

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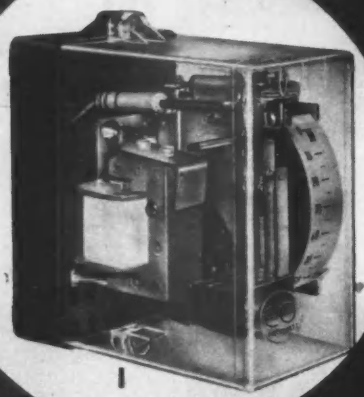

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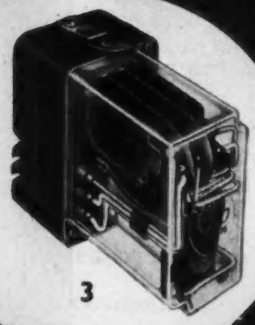

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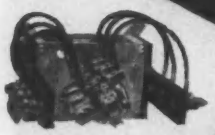

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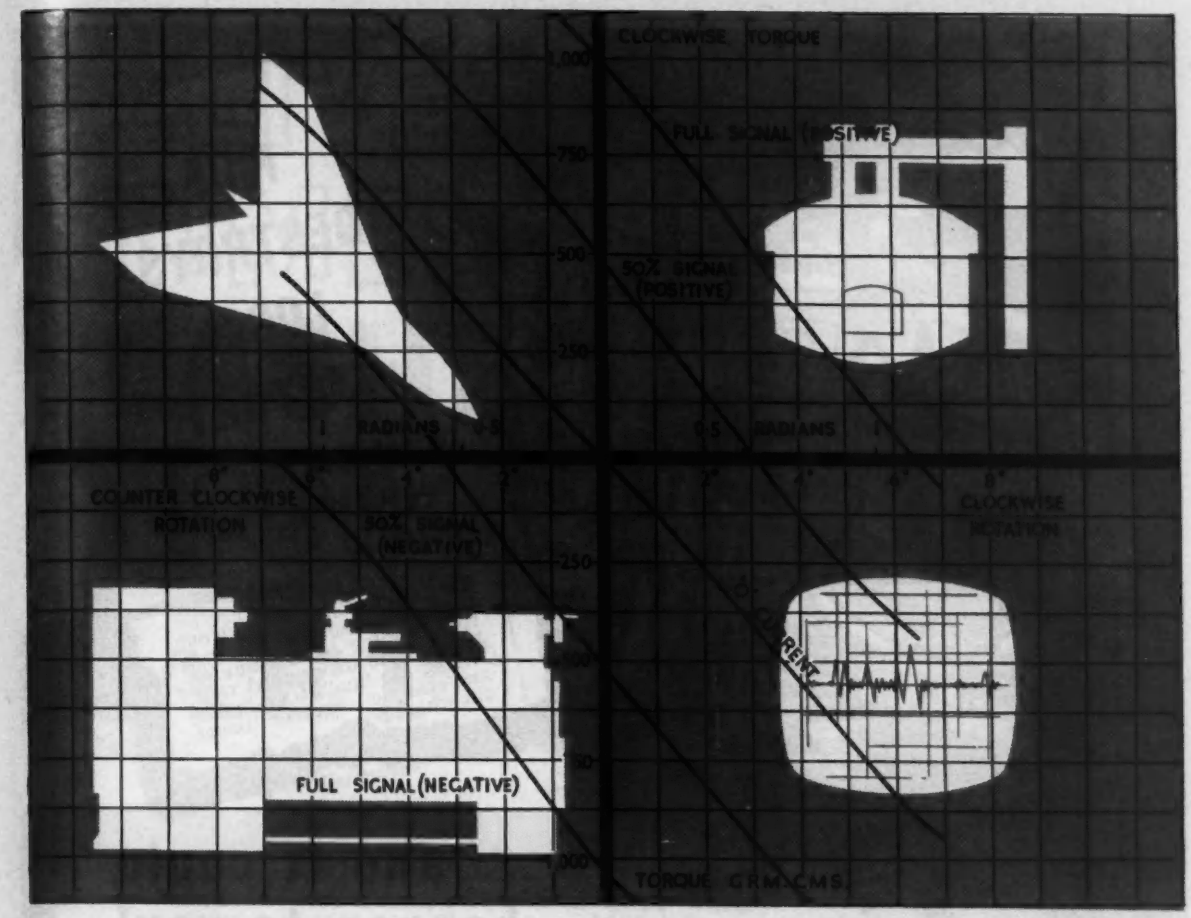

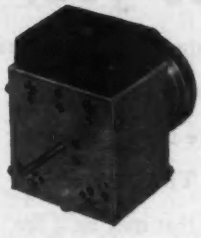

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Designed to operate under arduous conditions of flight at speeds in excess of that of sound, Elliott Torquemotors have special characteristics which make them ideal for industrial applications. Unaffected by vibration and sudden shock, reliable at extremes of temperature, these small, compact units are today used in applications ranging from furnace electrode level control to miniature electro-cardiographs. Elliott production line techniques make them available more quickly — and at lower cost — than any similar units. There is a Torquemotor from the Elliott range to meet your *precise* control requirements.

Illustrated: Type 276 with A.C. pick off for angular displacement feedback. Approx. 2.30" high, 1.805" wide, 1.320" deep. Normal working power 2.5 watts. Can be wound for a wide range of impedances.

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SERVO COMPONENTS DIVISION

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CENTURY WORKS · LEWISHAM · S E 13

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PAGE 3
FIRE DESTROYS LOCAL FACTORY
Electrical fault causes disastrous blaze
This afternoon, fire broke out in the new factory belonging to a leading local manufacturer. It is understood that, during the lunch time break, an electric motor burnt out which ca

...and it could happen to you!

In every factory where there are electric motors, there is the ever present danger of fire due to electrical faults such as single phasing and overloading — especially when starters are used that do not include the protection that is a basic part of the DUPAR TFK Starter.

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10" POTENTIOMETRIC RECORDERS

		SCALE			CHART SPEEDS				INPUT BRIDGE ENERGIZED BY:		LIST PRICE £
		Spans in mV		5-position zero supp. switch*†	1"-40" per hr.	5"-60" per hr.	1, 2, 3" per min. & per hr.	3, 6, 9, 15, 30 & 49" per hr.	CCSU	MERCURY CELL	
		10-50*	10-100*								
1	SINGLE POINT	✓							✓		385
2		✓								✓	248
3		✓					✓		✓		282
4		✓						✓	✓		282
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† Maximum scale span 50mV i.e. scale span of 5 mV gives :— 0 to 5, 5 to 10, 10 to 15, 15 to 20 and 20 to 25 mV.

Standard recorders have a speed response of 2 secs. for f.s.d. Printing speeds of 5 secs. and 15 secs. per point are available as standard.

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Instrumentation Division
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P.O. Box One · Harlow · Essex

- Reserve for me for 7 days pending firm order, recorder (s) as number ☐
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- Post to me complete technical literature on AEI range of recorders. ☐

AEI

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P.O. Box 1 · Harlow · Essex · Tel: Harlow 25271
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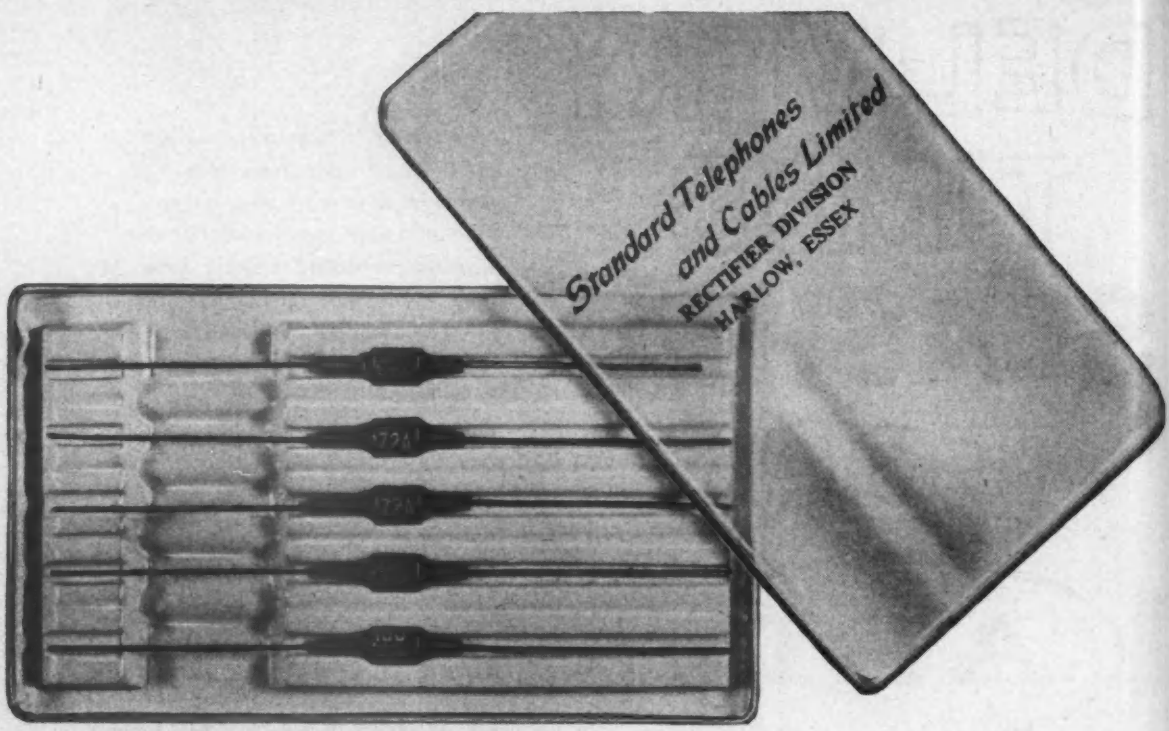
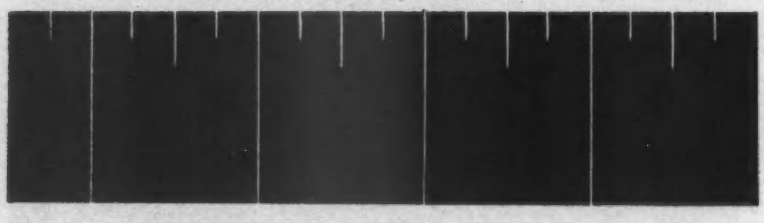


actual size



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- *The first complete range of close-tolerance ZENER Diodes available from production*

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Z2 SERIES ZENER DIODES		
±5% Voltage Tolerance (Red and Green Sleeves)	TYPE	NOMINAL VOLTAGE
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	Z2A36F	3.6
	Z2A39F	3.9
±10% Voltage Tolerance (Red and Yellow Sleeves)	Z2A43F	4.3
	Z2A47F	4.7
	Z2A51F	5.1
	Z2A56F	5.6
	Z2A62F	6.2
	Z2A68F	6.8
	Z2A75F	7.5
±20% Voltage Tolerance (Red and Blue Sleeves)	Z2A82F	8.2
	Z2A91F	9.1
	Z2A100F	10
	Z2A110F	11
	Z2A120F	12
	Z2A130F	13
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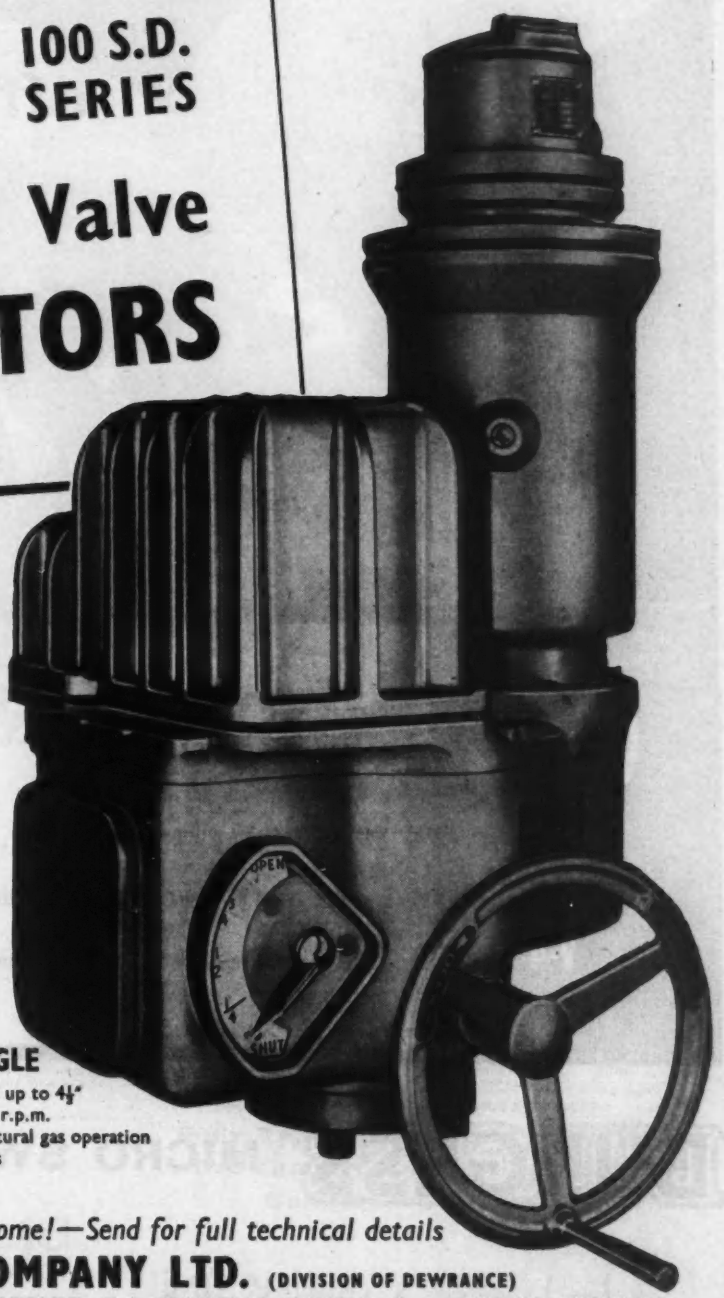

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Unit does not run in oil bath

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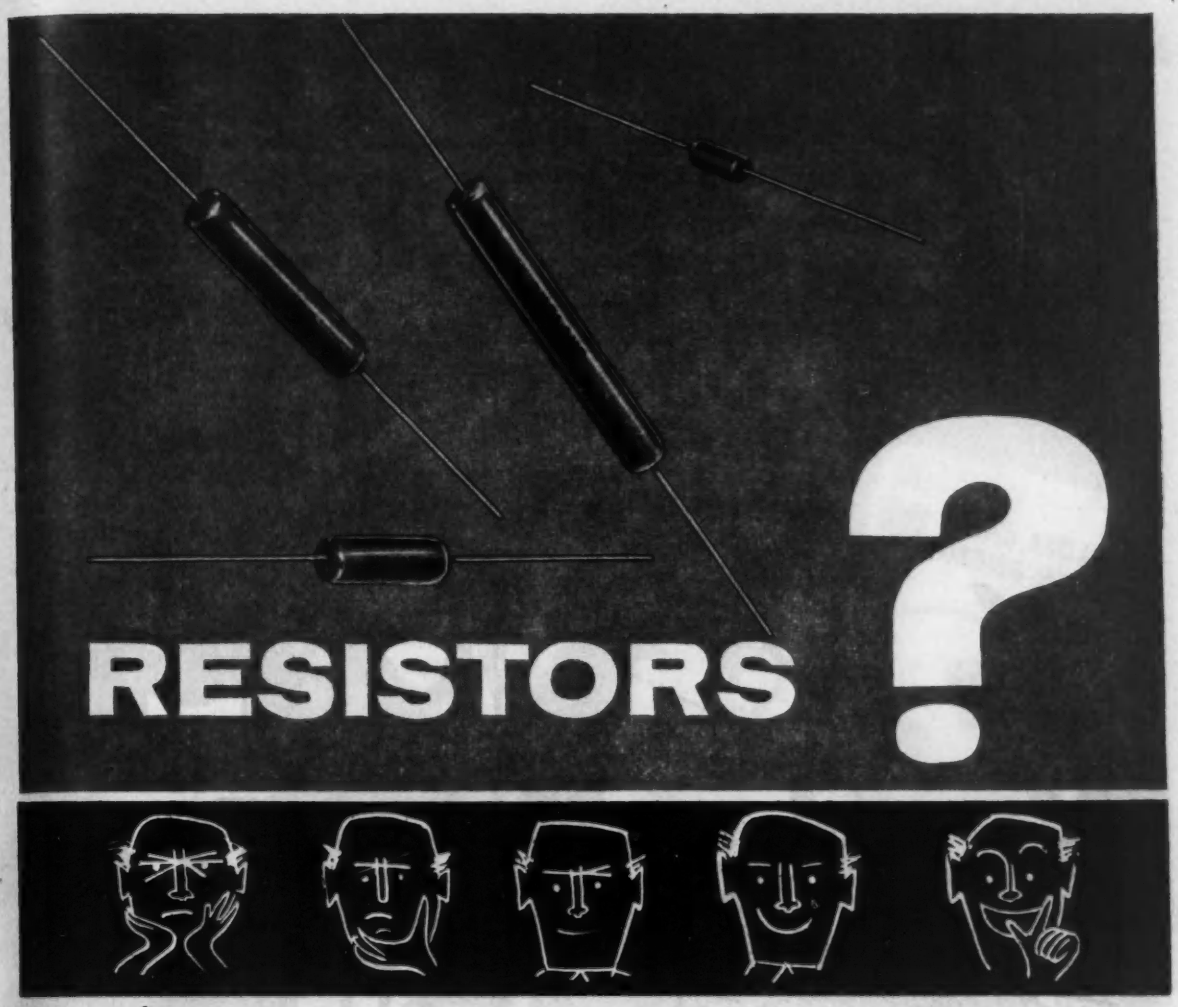

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Examples of our miniature range

Rating (at 20°C) Watts	TYPE	Resistance Range ohms		Tolerance
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7	301A	2	68,000	5%
10	302A	4	140,000	5%
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Westool components are among the finest available for electrical, electronic and electro-magnetic control. Every component is tested and re-tested at all stages of production to ensure complete accuracy and reliability.

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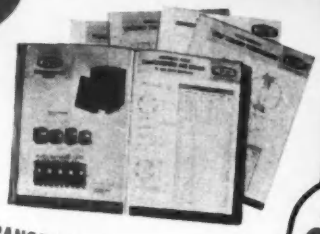
Westool Solenoids are simply but soundly designed. Entirely self-contained, compact—they can be fitted into any control system, remote, automatic or push-button. Action is instantaneous and certain. Wide standard range.



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Westool transformers range from the smallest possible up to 2000 VA for sealed can types and from 5kVA single-phase to 18kVA three-phase.

Transformers and chokes are made to customers' specifications—or designed to meet customers' specific needs.

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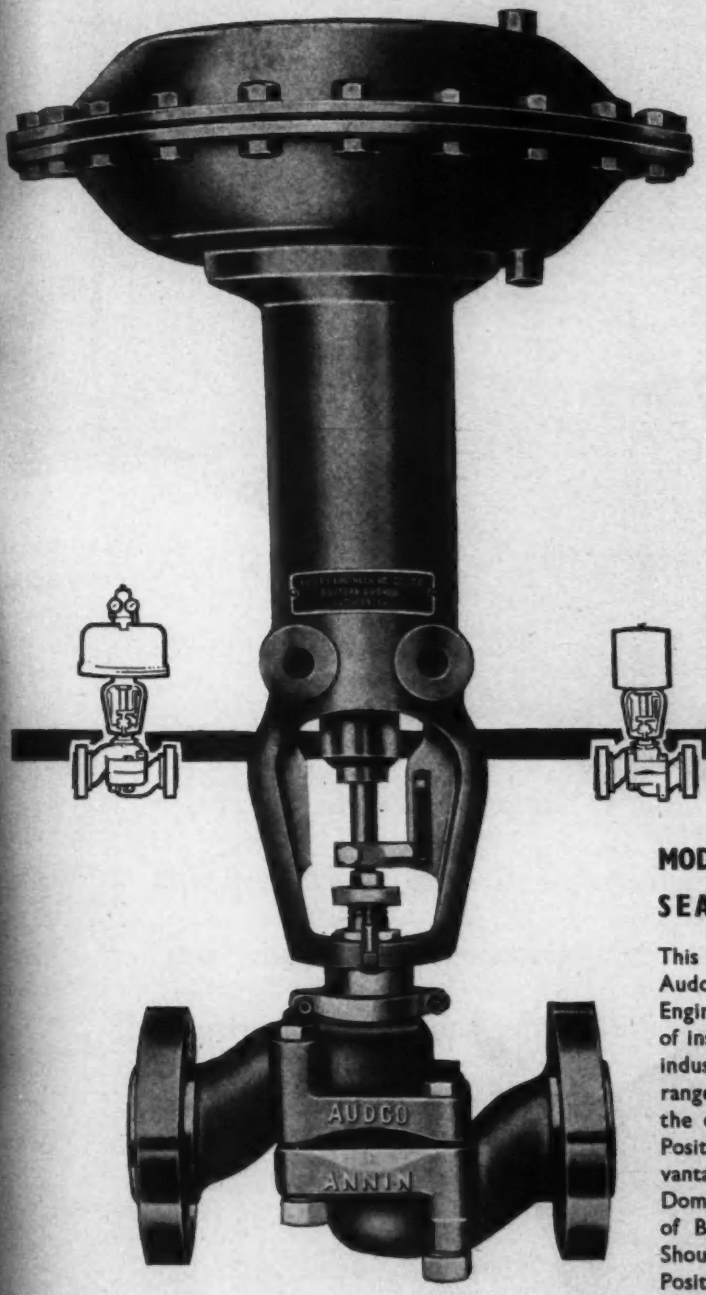

ANNOUNCING THE LATEST AUDCO CONTROL VALVE DEVELOPMENT

MODEL 1550 SPLIT BODY SINGLE SEATED DIAPHRAGM VALVE

This new valve has been developed by the Audco Control Valves Division of Audley Engineering Company Limited at the request of instrument engineers in a wide variety of industries. It is intended to supplement the range of Audco Domotor Control Valves for the engineer who does not want to use a Positioner. This model retains all the advantages of split body construction used with Domotor Operated Valves, and sub-assemblies of Body and Actuator are interchangeable. Should a change of service justify the use of a Positioner, it is possible to mount this on the top or side as desired. The valve body is produced in a variety of metals including cast iron, stainless steel and bronze, and is available in sizes up to 1", and will shortly be available in sizes up to 2".

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when are advertisements
are always telling news

When are advertisements telling?

Many people say, 'I never read advertisements.' And this is often true in the sense that they are not digested in the way, for example, articles are.

But nevertheless the 'messages' of advertisements do get home. (This is fortunate, for without advertising the selling price of many journals—including this one—would be prohibitive.)

The advertisements in *Control* contain up-to-date news of products, developments and services in an easily assimilable form. Go through the advertising in this issue—from beginning to end. Assuming your interest in the design, construction and maintenance of efficient systems of control, you will undoubtedly find that in a few minutes you have gained much valuable information.

Advertisements in *Control* are always telling news worth being told.

This is a PYE

TASC unit
TORQUE AND SPEED CONTROL

This Slash maintenance costs.
Eliminate special precautions against overloads.

is Give you local or remote control positively, simply and precisely.

what A TASC master (Torque) gives you full control between zero and rated torque.

the

TASC unit
TORQUE AND SPEED CONTROL

can A TASC master (speed) gives you a 20:1 speed range with good regulation, a smooth and fast take up and no cogging. With full torque available over the entire speed range.

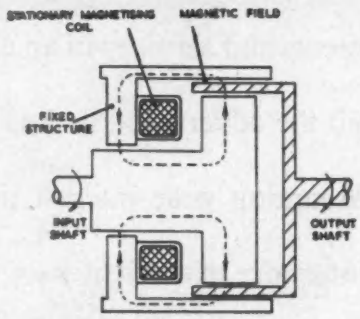
do A TASC master (special) can be devised to give you 50:1 speed range.

this is

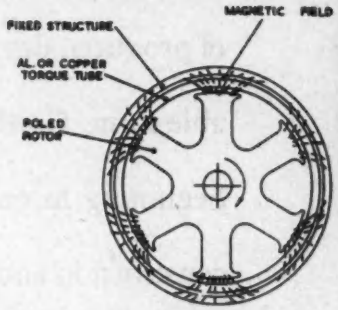
what the

TASC unit

is



The TASC unit is a new application of the Faraday disc principle.
It consists of two independently rotating members magnetically linked by the field from a fixed coil. The transmitted torque is proportional to the coil current. It is thus an inherently controlled torque device.



The TASC Unit is unaffected by stall-down on output no sliprings or brushes—low output inertia—no out-of-balance forces—sealed bearings—sizes from 1/4 to 10 h.p.

Find out more about the

TASC unit
TORQUE AND SPEED CONTROL

This coupon with your company letterhead will bring you full technical details and a demonstration at your works if you require it.

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COMPANY .....

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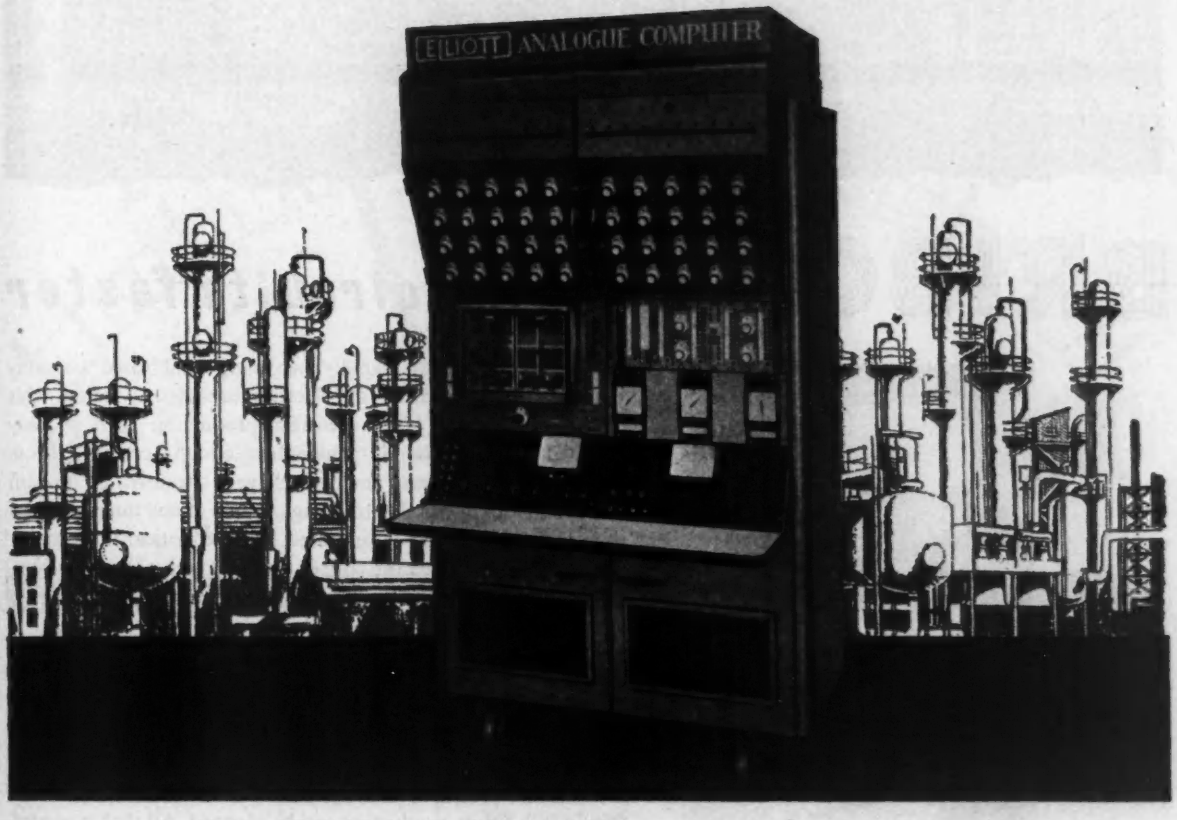
announce the G-PAC MK II
GENERAL PURPOSE ANALOGUE COMPUTER



The G-PAC MK II GENERAL PURPOSE ANALOGUE COMPUTER is the choice of the discerning engineer in all fields of industry for the solution of complex problems.

In the Chemical Engineering field.

* **STABILITY STUDY OF DISTILLATION AND FRACTIONATING COLUMNS**
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* **HEAT TRANSFER**

are examples of the wide range of applications in which G-PAC Mk II can considerably reduce days of tedious design study to hours.

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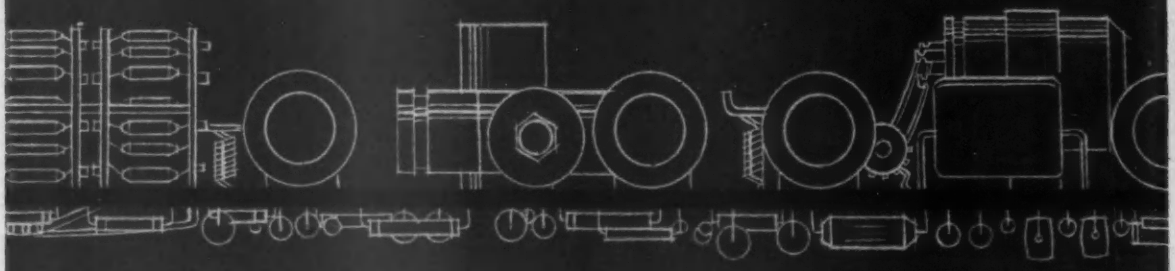
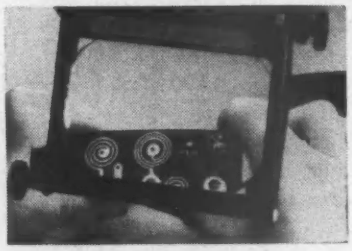
Speed is the need in Printed Circuits

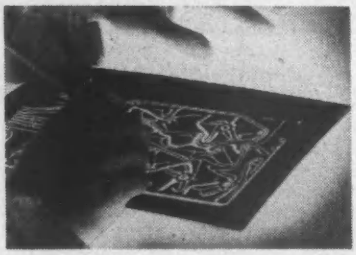


BRIBOND *print circuits faster*



The Printed Circuit is rapidly becoming established assembly practice in every field of electro-mechanics. Meeting this increasing demand takes specialist production such as only Bribond offers. Bribond manufacture circuits complete from design to finished board, and every stage is organised on modern line production methods providing outputs of any quantity. And each individual circuit is subjected to three critical inspections. This is increased when the copper is plated with either rhodium, silver, or gold.

BRIBOND *make prototypes quicker*



The prototype department is at the service of all Bribond customers. It can produce within 48 hours or less, the initial circuit from which future production can be planned. All that is needed is a clean circuit image from which reproduction can be made. Where desired, and time permits, the whole of this work can be carried out in our drawing office. Bribond recognise that quick prototypes—whether for complete units or small sub-assemblies—are essential in these highly competitive days when anything that shortens the time-lag between drawing board and production can mean a big reduction in marketing costs.

BRIBOND *maintain prompt deliveries*

Bribond have organised production to guarantee prompt delivery of customer's requirements. Consultation and planning of any form of printed circuit—double sided, component notated, flexible, flush surfaced, plated, etc.—is freely offered and your enquiry is invited.

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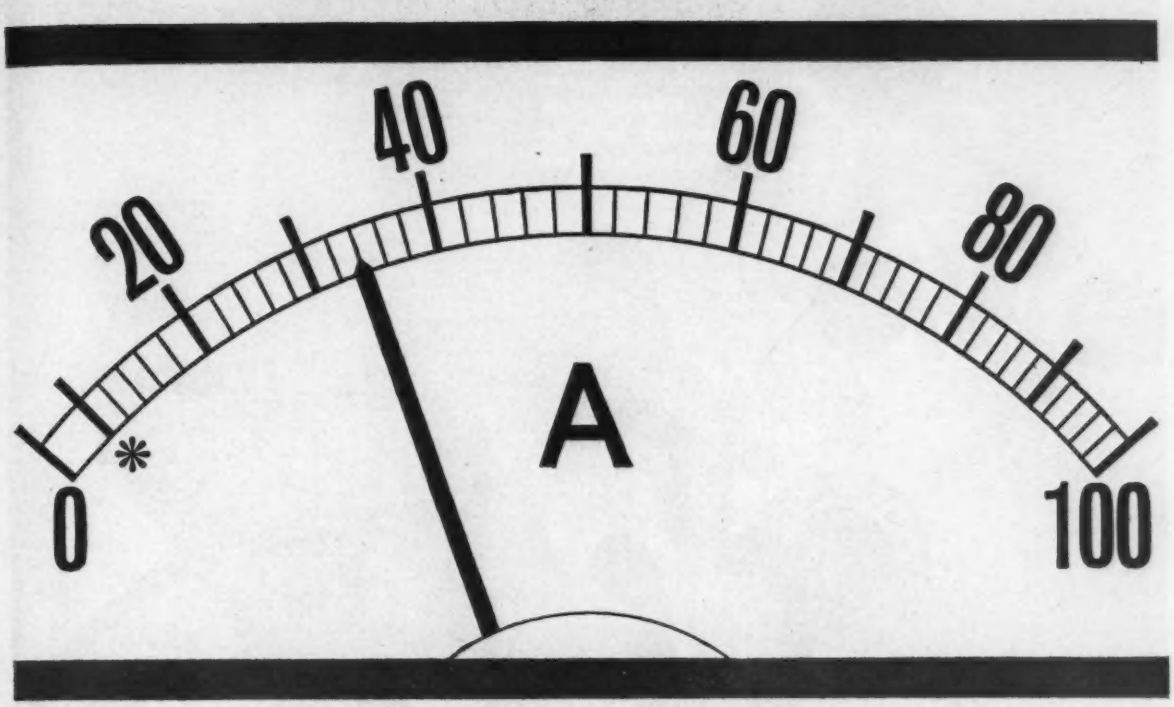

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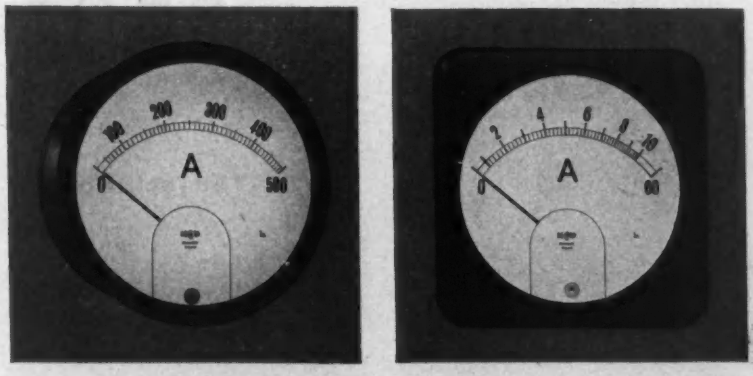

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The Southern Instruments system

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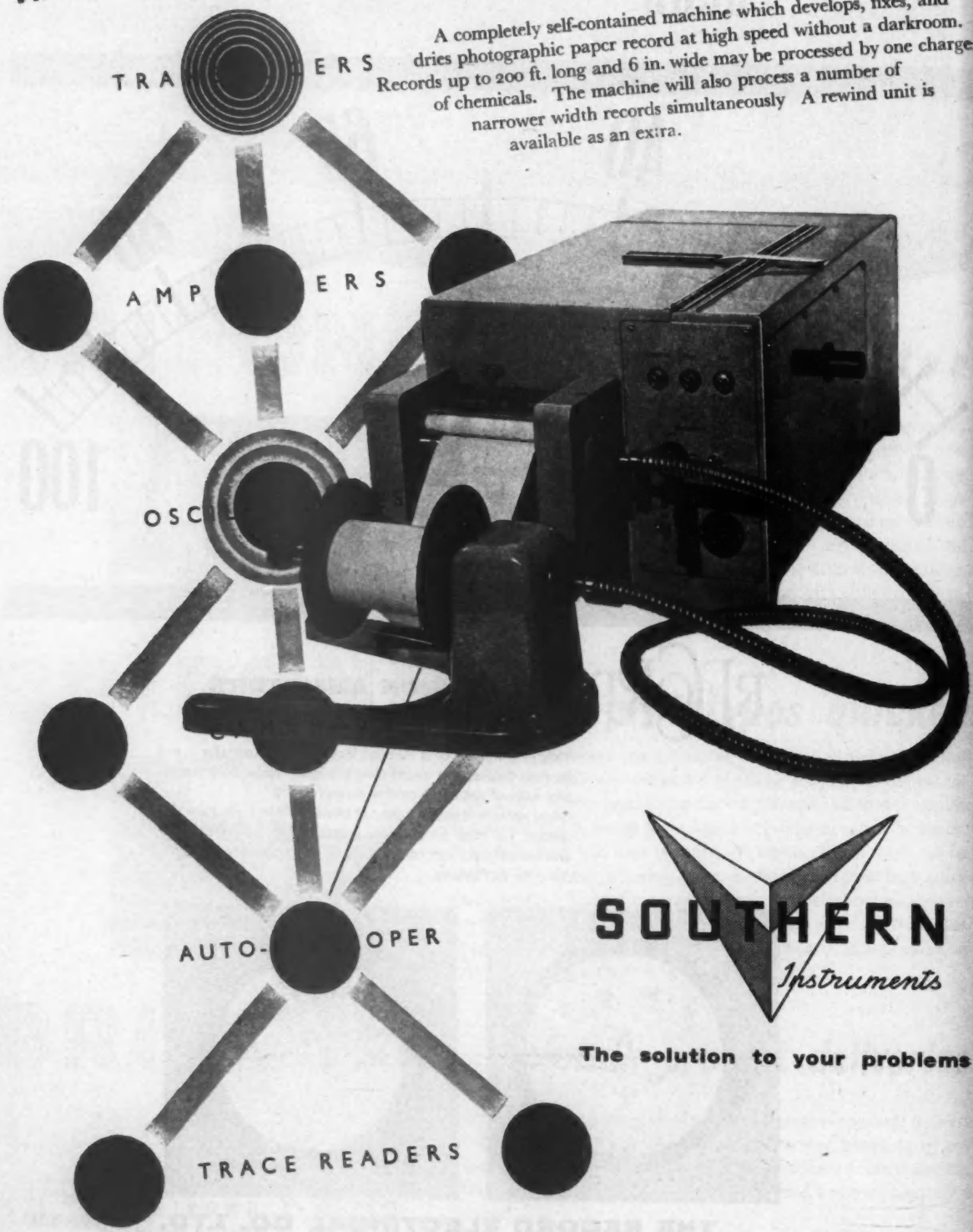
A completely self-contained machine which develops, fixes, and dries photographic paper record at high speed without a darkroom. Records up to 200 ft. long and 6 in. wide may be processed by one charge of chemicals. The machine will also process a number of narrower width records simultaneously A rewind unit is available as an extra.



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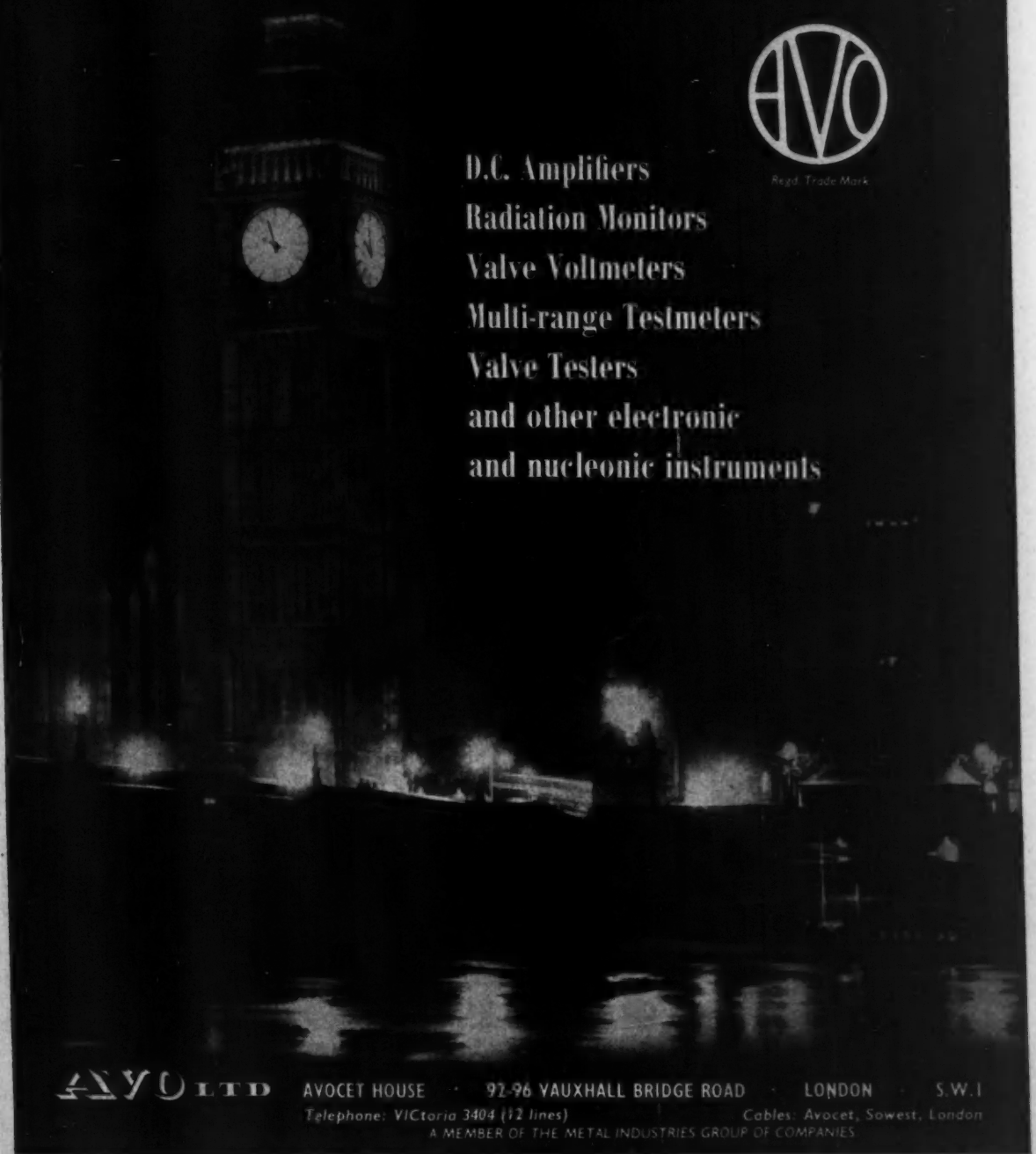

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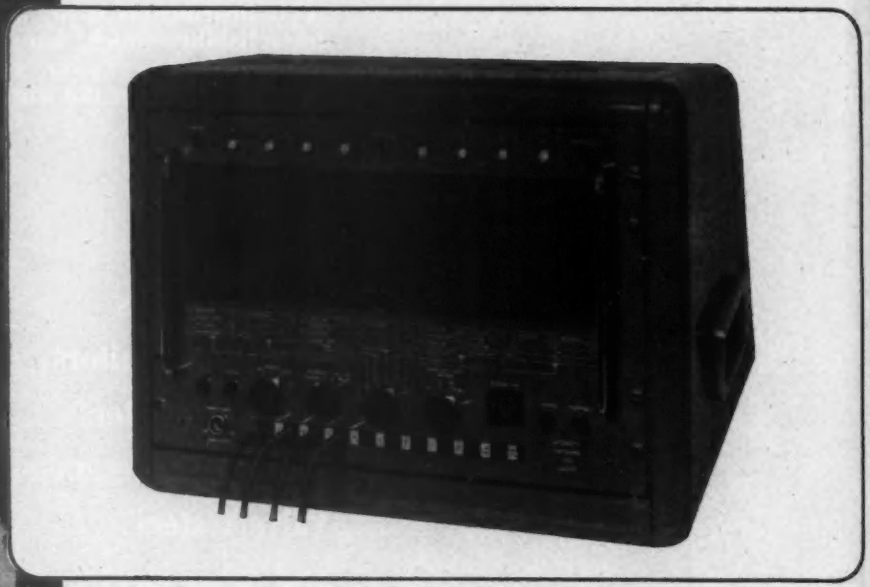

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Portable self-contained equipment automatically displaying a continuous analysis of channel utilisation and message totals from radio and telegraph networks.

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- ★ Details of the amount of traffic passed on every circuit under review.
- ★ The number of individual messages or transactions within the same period.
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- ★ Automatic camera recording of readings if required.
- ★ Analysis of several circuits simultaneously.

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it takes

to make a relay

NEW FOR PRINTED CIRCUITS!

To meet the increasing use of printed circuit techniques we now have available a range of 2, 4 and 6 pole printed circuit sockets for use with the complete range of Siemens and Halske Type 154 and 162 miniature relays.

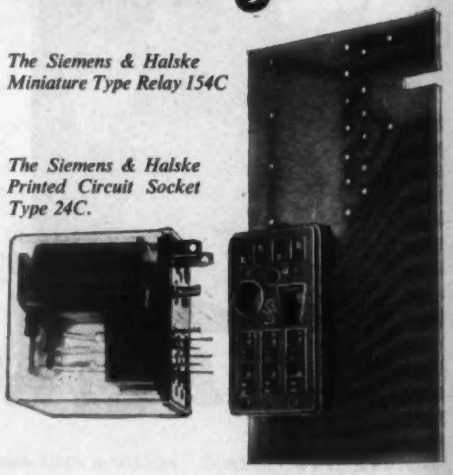
SEE THE ADVANTAGES!

*2, 4 and 6 pole sockets available *No 'bridge' connections needed *Pin spacing conforms to 0.15″ module *Socket pin sizes are correct for standard hole sizes in the printed board.

Full information and technical assistance on request.

The Siemens & Halske Miniature Type Relay 154C

The Siemens & Halske Printed Circuit Socket Type 24C.



B&R RELAYS LIMITED

B & R RELAYS LIMITED · **Temple Fields** · **Harlow** · **Essex**
Tel. Harlow 25231/4 Member of the Gas Purification Group

The Plannair 2½" Centrifugal Blower operates on 230V or 115V single phase 50 cycles.
Built in two types for right or left hand air delivery.

PLANNAIR & MARCONI MEETING IN CAMERA

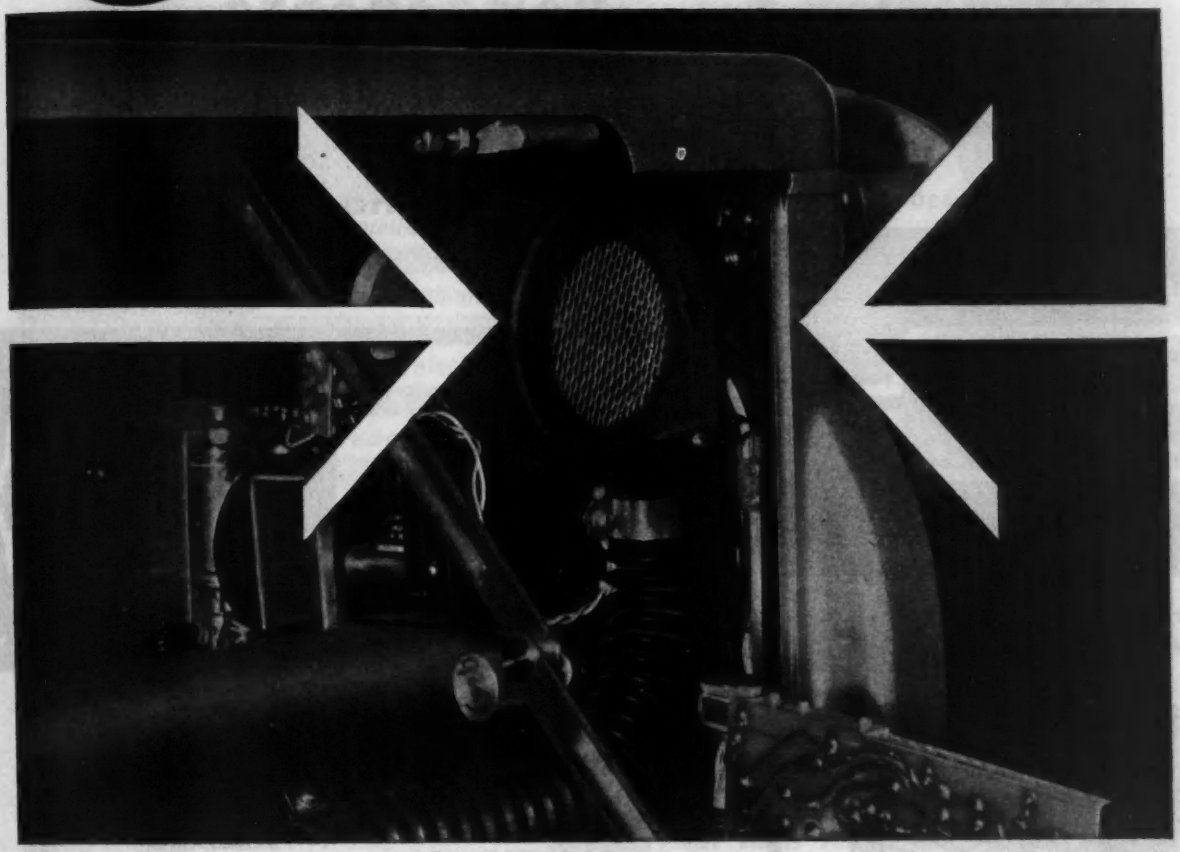


Illustration shows the Plannair 2½" Centrifugal Blower installed in the Marconi Mark IV TV camera.

There's nothing secret about it, however. It's quite usual for top people in electronics to turn to Plannair for whatever they need in temperature control equipment. That's one of the reasons why the Marconi Mark IV TV camera—which is currently casting a cool and calculating eye around many a TV studio—relies on the new Plannair 2½" centrifugal blower to keep things running smoothly when the heat's on. Secondly, Marconi—in common with others of their high reputation—share the knowledge that size to output, the Plannair range of blowers and wafters are the world's very best. They are also robust, silent and immensely reliable.

Send for the Plannair Centrifugal Blower Leaflet which gives full details of the units available.

Finally, should you run into difficulties in temperature control, may we suggest that you arrange a meeting with us? We can help you.

ANOTHER FINE APPLICATION OF THE PLANNAIR 2½" CENTRIFUGAL BLOWER

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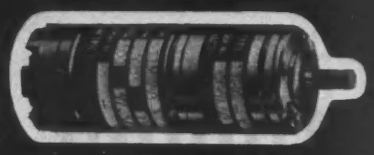
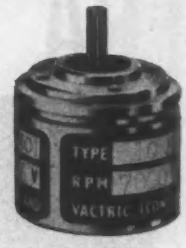
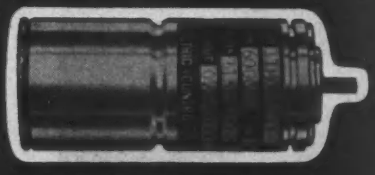


In-line gearhead coupled to servo motor.

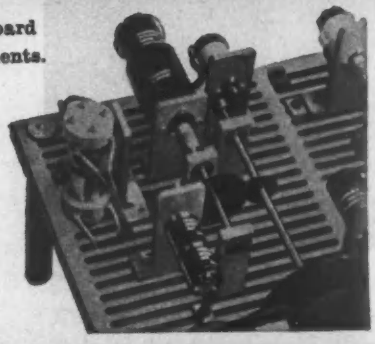


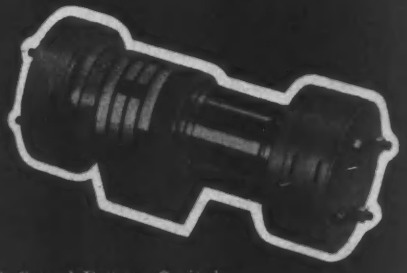
Size 10 A.C. Motor.



Size 11 A.C. Motor Tachogenerator.

Breadboard Components.





High Speed Rotary Switch.

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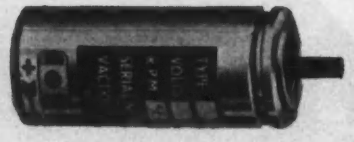
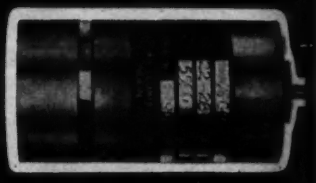
Precision Servo Components

for missiles aircraft and automation



Size 08 D.C. Motor.



PG 800 D.C. Governed M

IN-LINE GEARHEADS.
Low-inertia, low backlash precision reductions gearheads in International frame Sizes 10, 11 and 15, ratios up to 1000:1. Can be directly coupled to International Frame size servo motors, synchros, potentiometers, etc.

D.C. SERVO MOTORS.
Miniature precision built ball bearing motors with permanent magnet field. International frame Sizes 08, 11, 15 and 18 or 'P' series. All motors are reversible and can be used as generators.

A.C. SERVO MOTORS.
Precision-built, low inertia motors 2-phase 400 c/s or 50 c/s in International frame sizes 07, 10, 11, 15 and 18.

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P.800 D.C. Motor fitted with centrifugally operated governer. External power transistor circuit handles 97% of armature current.

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Combined 2-phase servo motor and low inertia drag-cup generator, low residual voltage and good linearity. International frame sizes 10 and 11.

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A wide range of standard supports, shafting, gears, differentials, etc., for breadboarding servo systems. All parts made from first class materials and manufactured to close tolerances for ease of assembly.

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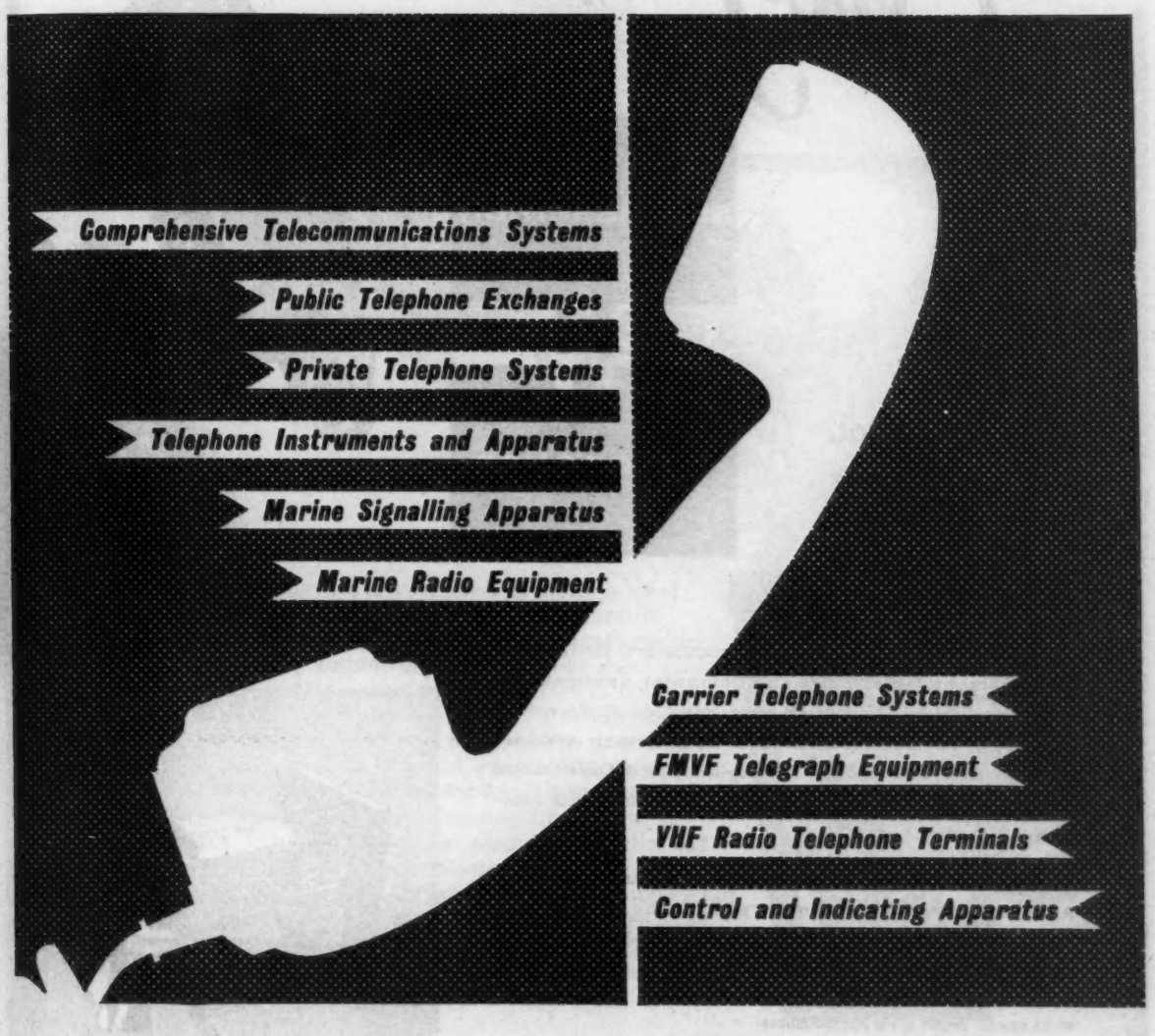

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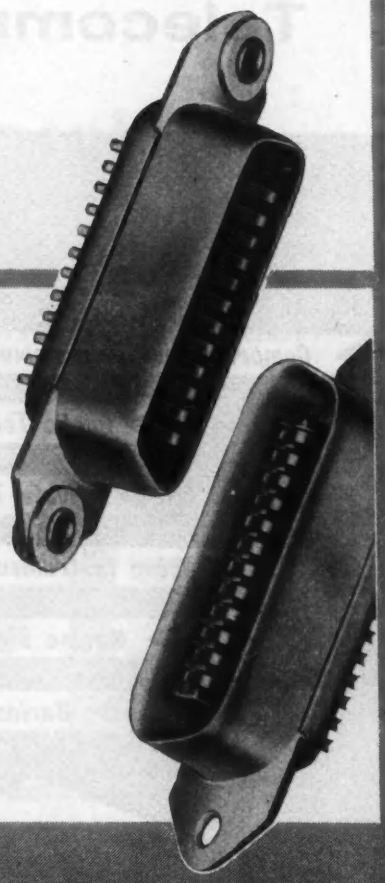

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Offering outstanding advantages, particularly to the designer of equipment for aircraft and computer applications, Amphenol Micro-Ribbons feature valuable space-saving and weight-saving characteristics. Despite their compact size they nevertheless allow full exploitation of their unique ribbon contact features in miniature applications with complete reliability.

With types available offering up to as many as 50 contacts, Amphenol Micro-Ribbons make possible the connection of many circuits and sub-units with considerable economy of space and weight.

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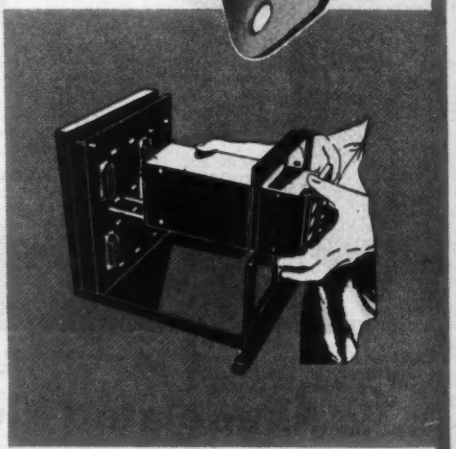

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WE MAY HAVE THE ANSWER!

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Whatever the pressure, the application, or the temperature, one of the wide range of Black Control Valves is likely to meet your exact need—and if it doesn't—if it *can* be made—we can make one for you that will. Solenoid or diaphragm operated for general industrial applications or the more specialised requirements of the aircraft, guided missile or nuclear fields, Blacks may have the answer.

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The Black range of Pressure Switches has been designed for all kinds of pressure signalling and control not only for industrial applications but in the more specialised field of missile and nuclear research.

Specified by a rapidly increasing number of leading organisations throughout the country they are available for an extremely wide and accurate range of pressures—either standard or purpose made.
Send us your enquiry. Whatever the size, application, temperature or material—let us know your requirements—we are almost certain to be of assistance.

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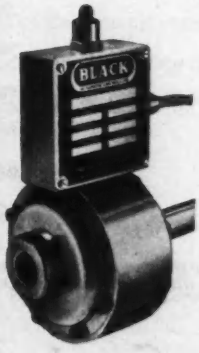
HDO Fuel Oil Valve. Size ⅛"—¼" B.S.P. Low pressure, minimum pressure drop.

ST/2/B Straight Through in-line Valve. Air, gas or light oil. Pressures up to 100 p.s.i. Size ⅛", ¼" B.S.P.

DPS MKII Differential Pressure Switch. Standard pattern. Range 0-30" w.g. 30"-10 p.s.i. Details of high static and high differential models on request.

PRESSURE SWITCHES



FS MKII Flow Switch.
To indicate flow failure, reduction in flow to calibrated value or indicating delivery blockage. Standard model size ⅛" B.S.P.—¼" B.S.P. Other models in sizes up to 14".

VHPS High Pressure Switch. Fully adjustable, piston operated. Pressure range up to 10,000 p.s.i.

DPS MKIV Differential Pressure Switch. Stainless steel construction specially designed for Nuclear Power Stations. High static, high temperature. Medium CO_2. Pressure 300 p.s.i. Temperature 250°C.

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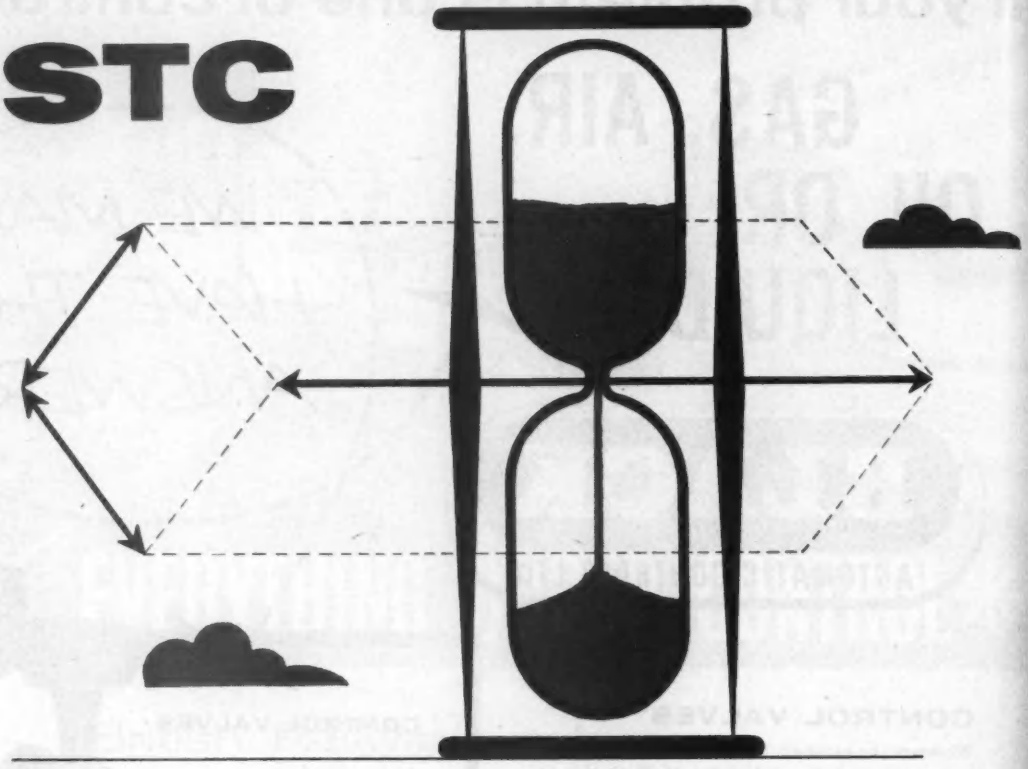
STC



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The fourth dimension, time—invisible and intangible, but in the case of STC components, definable in terms of sustained, faultless performance—is a very definite factor incorporated in their design and manufacture.

Such dependability is very necessary in view of the vital functions that STC components have to perform—in equipment for communications, navigation and remote control; and it is the reason why STC components are trusted implicitly by manufacturers of electronic equipment all over the world.

Get to know the range of STC Components—write for booklet M/103 which lists all components and their relevant technical literature.

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VOLTAGE CONTROL

A range of A.C. Mains Voltage Stabilisers which incorporate electronic detector systems of new design. They are robust, reliable and very compact.
The unit shown has a rating of 2.5 KVA, will handle input variations from 200-250 Volts whilst maintaining a pre-set controlled voltage between 220-240 Volts to an accuracy of ± 0.5%
This particular Stabiliser is suitable for bench, floor or wall mounting and is fitted into a steel case attractively finished in hammered aluminium. Dimensions are: Height 15", Width 10", Depth 7½".

Torovolts are the new toroidally wound continuously variable auto-transformers. Electrical and mechanical improvements have been incorporated to give greater safety and reliability. Legible dials ensure maximum convenience in use.

Expamet-Cressall resistors, rheostats and heaters form the most comprehensive range available from a single source. Units to control loads from 4 watts to over 20,000 Kilowatts are already in use all over the world. To widen still further the enormous field of applications of Expamet-Cressall products, two new designs have been introduced and are briefly described here. Further details and technical advice from our engineers is freely available.

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The Electrical Division of
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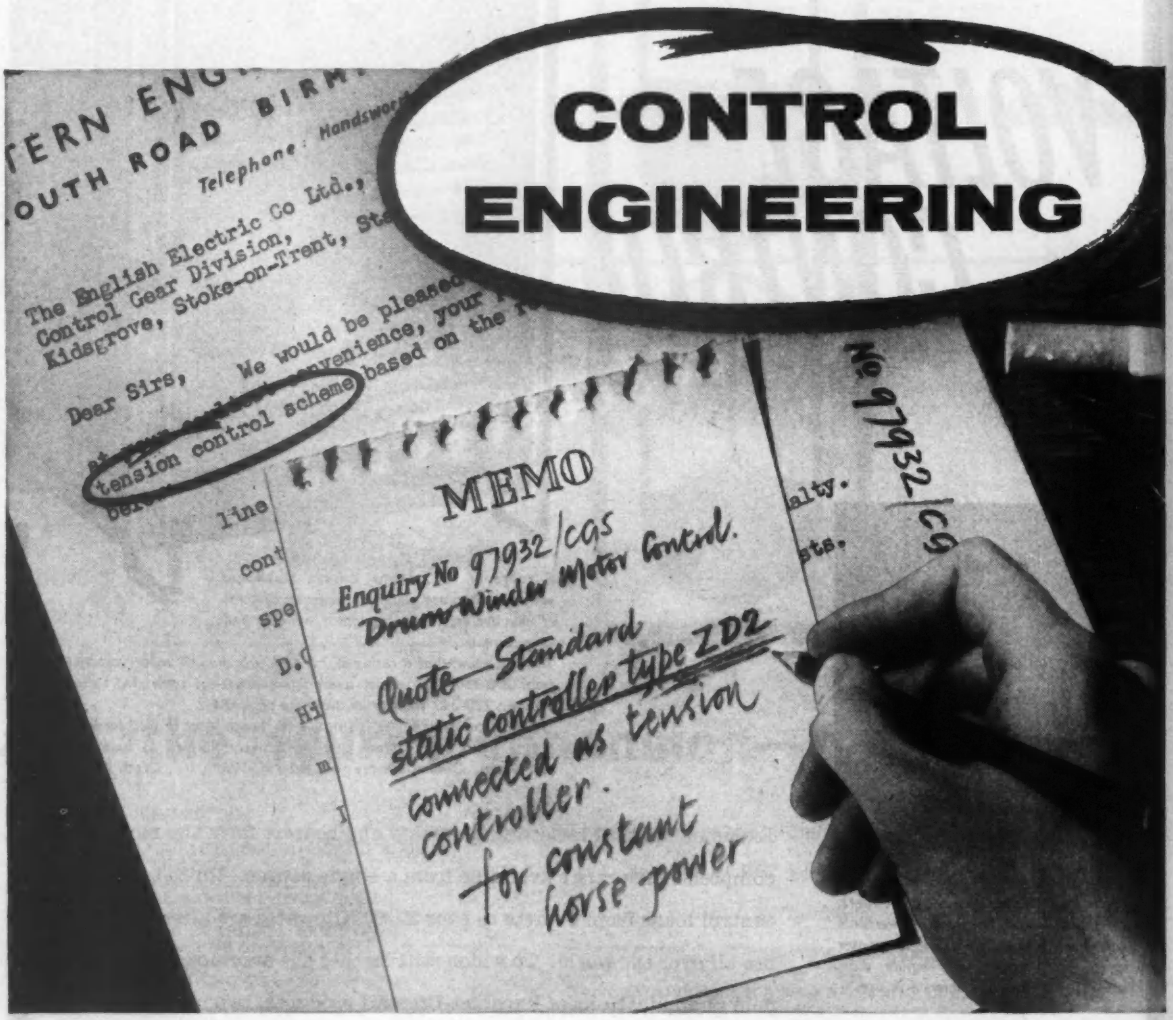

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type ZD2 (A.C. Supplies/Static Controller/D.C. Motor), extends from ¼ horse power to 100 horse power. These drives have a wide speed range and close regulation with inherent field failure protection and current limit protection.

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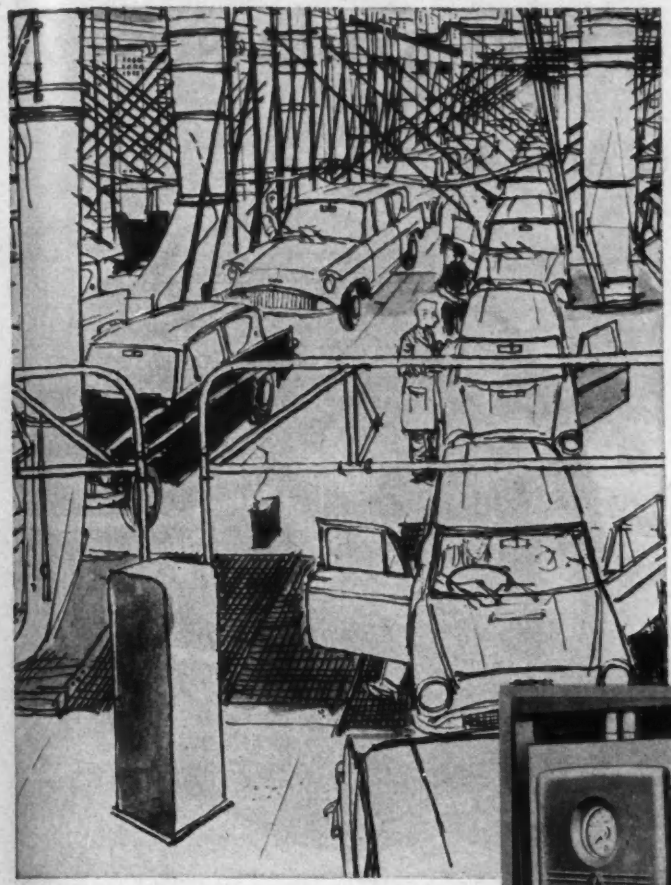
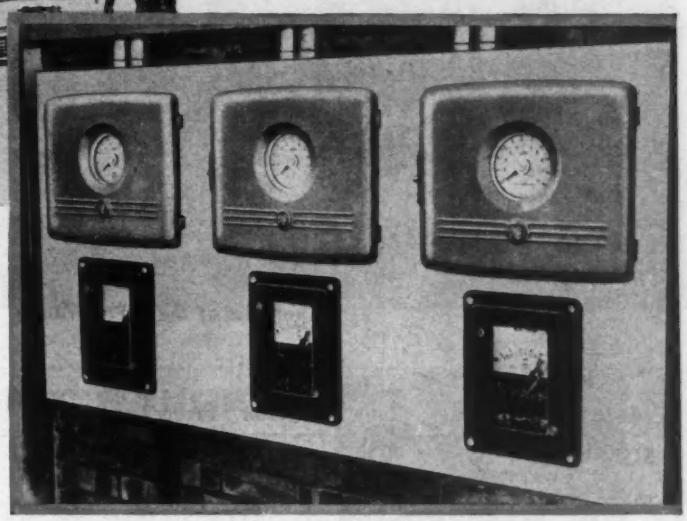
Control Gear Division, Kidsgrove, Stoke-on-Trent, Staffs. Telephone: Kidsgrove 2141/3
CG.2 WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON



FORD

chose Pye pH meters



In the Paint, Trim and Assembly Building recently completed at Dagenham, Ford created the most modern plant of its kind in the world. Pye were proud to supply the pH equipment which was specified.

Efficient pH measurement and control is improving quality, cutting costs and reducing manhours in factories all over the world. In highly specialised industries, which often rely on traditional process methods, chemists and engineers have realised that their problems too can be simplified by pH control. At Pye, an Applications Department exists solely to help customers with their instrumentation problems. This Department can advise on the suitability of pH Measurement and can specify or, if necessary, engineer complete pH control methods. You are invited to make full use of this new service to industry.

Please write for pH Application Sheets and leaflets describing Industrial pH Equipment.

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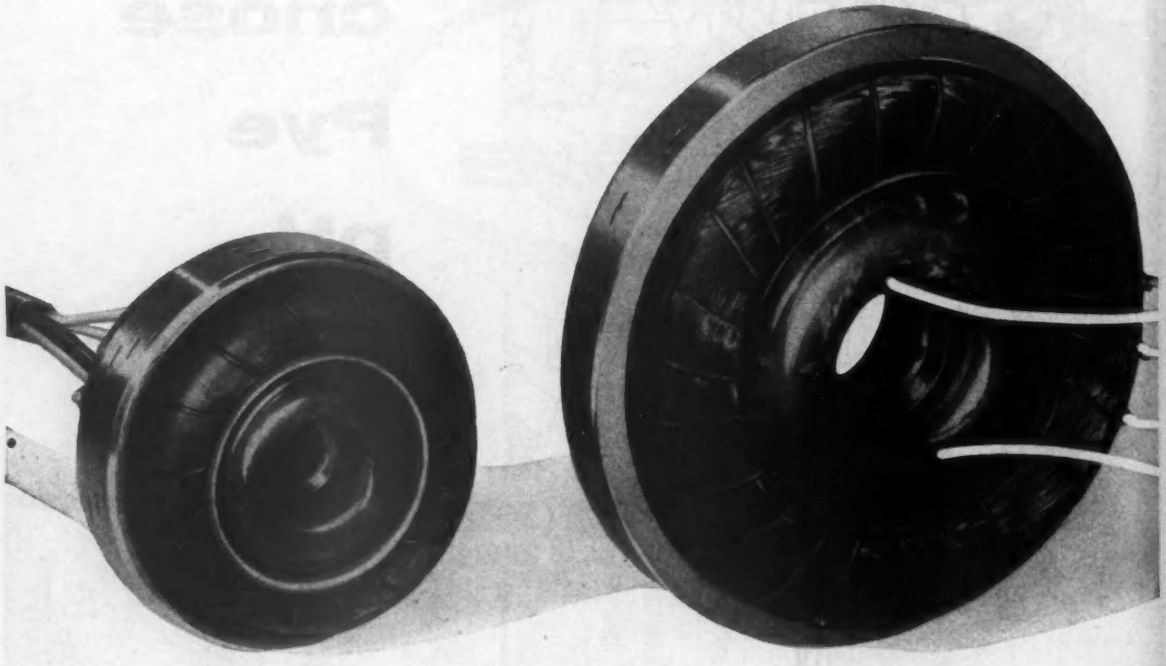
"SLAB" TYPE SYNCHROS

SIZES 15 AND 23



Examples of the Sperry range

Code Reference	Size	Voltage Rotor	Voltage Stator	Frequency	Function
S15RS4SL	15	0-20	0-20	400 c/s	Resolver
S23RS4SL	23	0-60	0-60	400 c/s	Resolver
S23CX4SL	23	115	15	400 c/s	Control Transmitter
S23CT4SL	23	1·4v/deg.	15	400 c/s	Control Transformer
S23CDX4SL	23	15	15	400 c/s	Control Differential Transmitter

SPERRY

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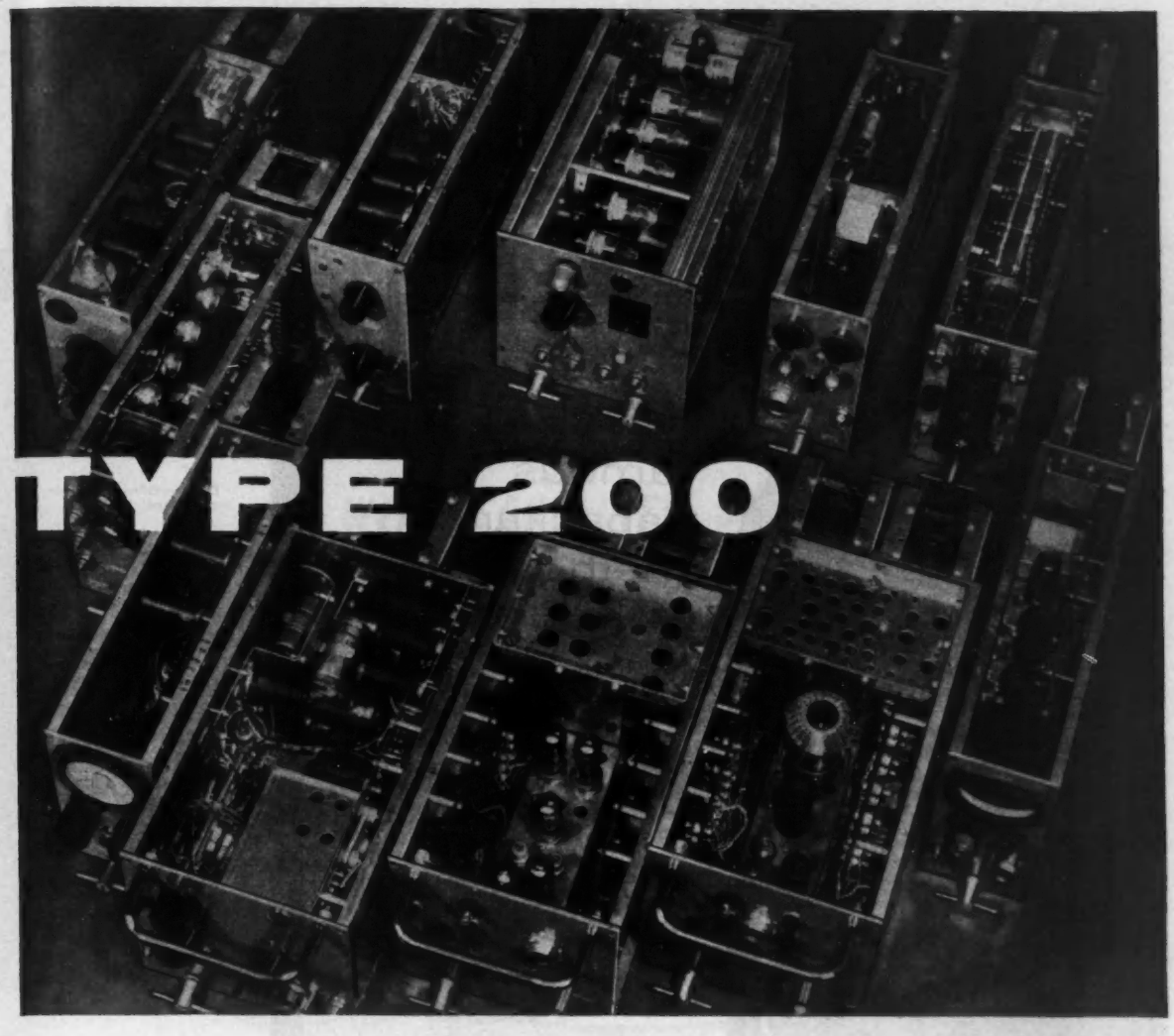
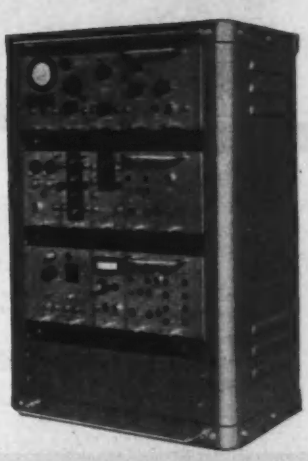


UNITIZED NUCLEONIC RANGE

The plan behind this Type 200 equipment is to offer you a Unitized Range (already 24 units and still increasing) not only to cover every type of nucleonic counting, but one that can be added to at will, so that you get only what you want, when you want.

- **Suitable for all types of nucleonic detectors.**
- **Built to a stringent specification.**
- **Designed in conjunction with A.E.R.E. Harwell.**
- **Flexible in use—a unit for every purpose.**



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INSTRUMENT DIVISION

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ERICSSON

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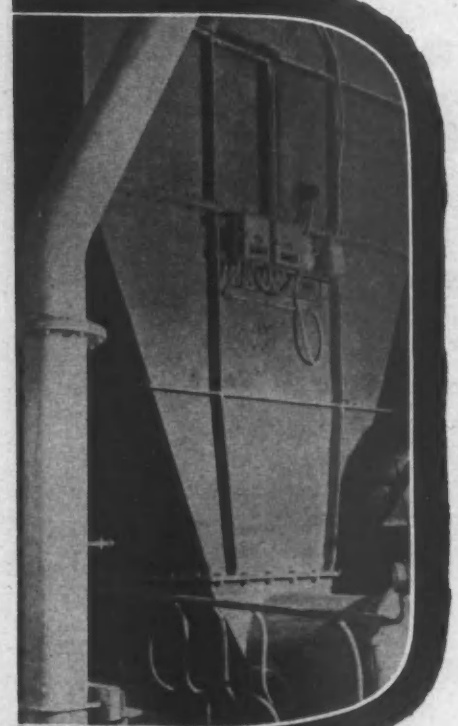
in Level Control

with the now famous capacitance method



The principle of electrical capacity is employed to detect the approach of any substance to (or recession from) the probe. The consequent change in capacitance is made to actuate a relay in the Fielden Tektor which can switch in an audible or visible alarm for high level and/or low level control of liquids or solids. Alternatively, it can control in a container the material at a predetermined level.
Since operation does not rely on contact with the substance the probe can be covered with anti-corrosive and heat-resistant insulation if required.

Easily installed and simply maintained.

No moving parts in or on the container.

Electronic unit can be up to 150 feet from the container.

Multiple Tektor units can be supplied in one control panel for centralised level control where a number of control points exist, thus saving considerably in installation costs.

Simplicity of design and printed circuits ensure exceptional reliability. A wide range of probes for use with all materials — ranging from fine powders to run-of-the-mine coal, acids to bases, conductors to insulators — at varying temperatures and pressures.

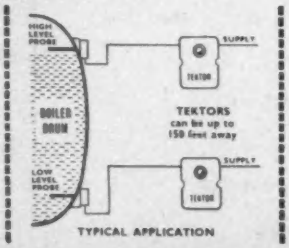
12

years experience

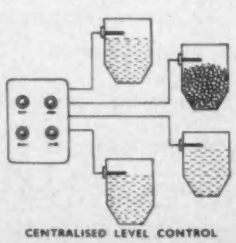
is behind every Fielden level controller and indicator — backed by first grade Application, Commissioning and Servicing Facilities.

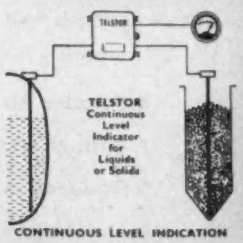
Over 100,000 Tektors and Telstors in operation throughout the world.

Illustration above shows a hopper at G. & T. Earle Ltd., Fielden high and low level Tektors are fitted to provide efficient packaging of cement by preventing overflow or running empty.



TYPICAL APPLICATION


CENTRALISED LEVEL CONTROL



CONTINUOUS LEVEL INDICATION

Fielden

WRITE FOR LEAFLET GL1/C

FIELDEN ELECTRONICS LTD · WYTHENSHAWE · MANCHESTER Phone: Wythenshawe 3251 (4 lines) Grams: Humidity Manchester
ALSO AUSTRALIA, ITALY AND CANADA *Branch Offices:* LONDON, WALSALL, STOCKTON-ON-TEES, EDINBURGH (A. R. BOLTON LTD), AND DUBLIN.
Agents throughout the world

Indicating Recording Control

TT4

Circle **No 49** on reply card for further details

Thousands of firms have *already* proved that the 'TRANSITROL' Regd.

COMBINES MAXIMUM RELIABILITY WITH LONG-LIFE SERVICE

TYPE 990: Two-position (on/off) Controller
TYPE 991: Anticipatory Controller
TYPE 992: Proportioning (stepless) Controller
TYPE 993: Three-position Controller
TYPE 994: Programme Controller
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from **£35 · 10s**
DELIVERED

Since 1956, *when Ether Ltd. invented the transistorised indicating temperature-controller, thousands of these remarkable, direct-deflection instruments have been supplied to the STEEL, PLASTICS, RUBBER, CHEMICAL and PETROLEUM industries at home and overseas.*

Ether Transitrol Controllers, essentially simple in design, are accurate, reliable and surprisingly inexpensive. They employ no thermionic valves and they require no warming-up time. Ether Transitrol Controllers were the first in the field; they are still the finest.

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EST. 1927

* P.E control

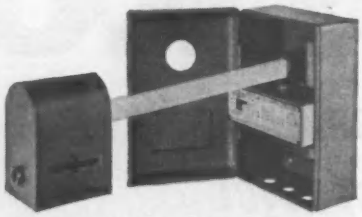

Photo-electric relay type Q.56
Uses include:—on-off switching; automatic spraying; length cutting gauge; conveyor control; process control; height gauge; limit switch; loop control; warning device; paper breakage indicators; alarms, etc. etc.

"Metoload" relay
Many factors can be measured or guarded against by keeping a check on the current of a driving motor. The Relay senses the torque of a driving motor and responding immediately to load variations, switches off the motor, indicates the variations or performs some other desired operation.

Counting and batching
Counting rates up to 20,000 per minute can be recorded and batching units divert succeeding articles after a chosen number has passed through the light beam.

There isn't a production plant anywhere that couldn't be made (or hasn't been made) more efficient, more economical by the use of Radiovisor Photo-electric and Electronic Controls

* **P.E.** is photo-electric

It costs nothing to consult us—
We have over thirty years' experience

RADIOVISOR P.E control

MAKERS OF THE MOST COMPREHENSIVE RANGE OF PHOTO-ELECTRIC CONTROLS IN THE WORLD

Standard photo-electric equipment include:—

Flamestat Flame Failure Control • Smoke Detector Fire Alarm Sequence Control • Counting and Batching Unit • Invisible Ray Burglar Alarm • Turbidity Equipment • Hopper and Bunker Level Control • Print Registration • Photo-electric Safety Guard • Factory Lighting Control • Automatic Radiation Pyrostat • Automatic Door Opening • Industrial Smoke Density Indicator and Alarm

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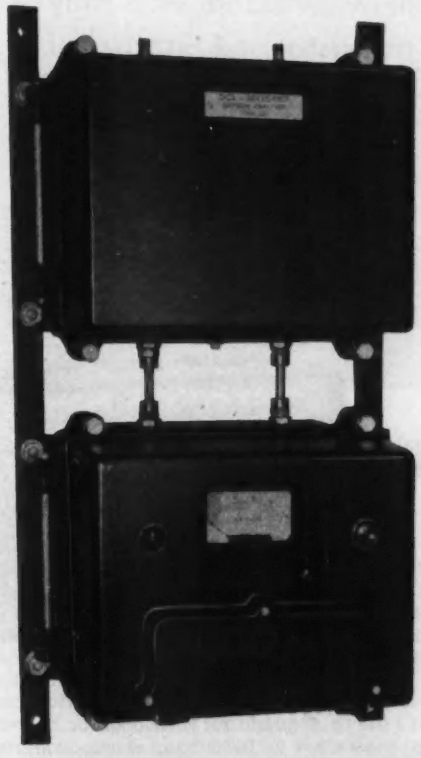
a new approach to oxygen analyser design

GIVES FASTER RESPONSE, SAFER AND EASIER OPERATION, GREATER RELIABILITY AND ACCURACY, WIDE RANGE—FLEXIBILITY EXTREME RUGGEDNESS—



An all-British analyser designed specifically for arduous chemical plant service.

Faraday's direct method for measuring magnetic susceptibility has been modernised to give a rapid and specific measurement free from the technical snags of the magnetic wind principle. The delicate suspension is replaced by rare metal, providing a virtually unbreakable measuring system. The analyser is ideal for boiler control and chemical process use.

* *F.S.D. 1% to 100% in six ranges*
* *Rapid response—95% response to input step-change achieved in 8 seconds with maximum sample flow-rate*
* *Metal dumb-bell suspension proved against shocks of 2,000 g*
* *Unaffected by viscosity, thermal conductivity and density, and insensitive to tilting and changes in sample flow rate*
* *Proved by years of plant use*

Full details and expert technical advice from

SERVOMEX CONTROLS LIMITED
(Chemical Instruments Division)
CROWBOROUGH SUSSEX
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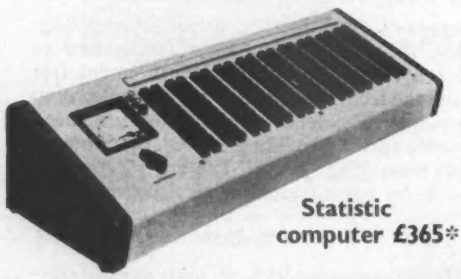
DCL SERVOMEX **Oxygen Analyser type 83**

GPS

GENERAL PRECISION SYSTEMS LIMITED

Are pleased to announce

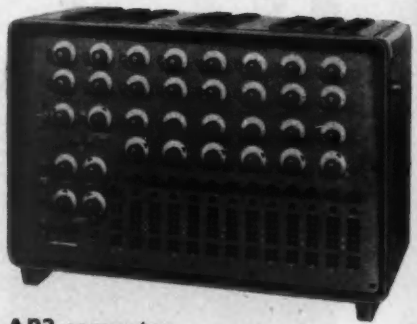
The conclusion of an agreement to sell and manufacture computing equipment designed by the well-known Swiss firm of Güttinger.



Statistic computer £365*

Now available is a fully transistorised statistical computer for determining directly Mean Value and Standard Deviation of up to 600 pieces in 10 classes.

Also available is a 12-amplifier compact, desk size, analogue computer for solution of linear differential equations. Six of the amplifiers may be used as integrators. Sixteen coefficient potentiometers are provided for parameter setting. The computer may be used in single-shot or repetitive mode.



AR2 computer £1100*

* Discount is allowable to educational establishments approved by the Ministry of Education.

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Electronic Constant Voltage Transformer for Airfield Direction Finding Equipment.

When so much depends upon accurate voltage control . . .

VITAL communications as well as industrial processing equipment frequently depend upon accurate control of the voltages which activate sensing, signalling and motivating devices. Variations due to load changes or supply fluctuations may seriously distort indicated values.

Foster voltage regulating equipment automatically detects and compensates for changes, so that installation performance is unaffected by variations in supply voltage and frequency, load and load power factor. Foster Transformers Limited are transformer, test and voltage regulation specialists to the world's electrical industries. Foster equipment — the widest and most varied available — is supplied through Branches and Agents in 36 countries.

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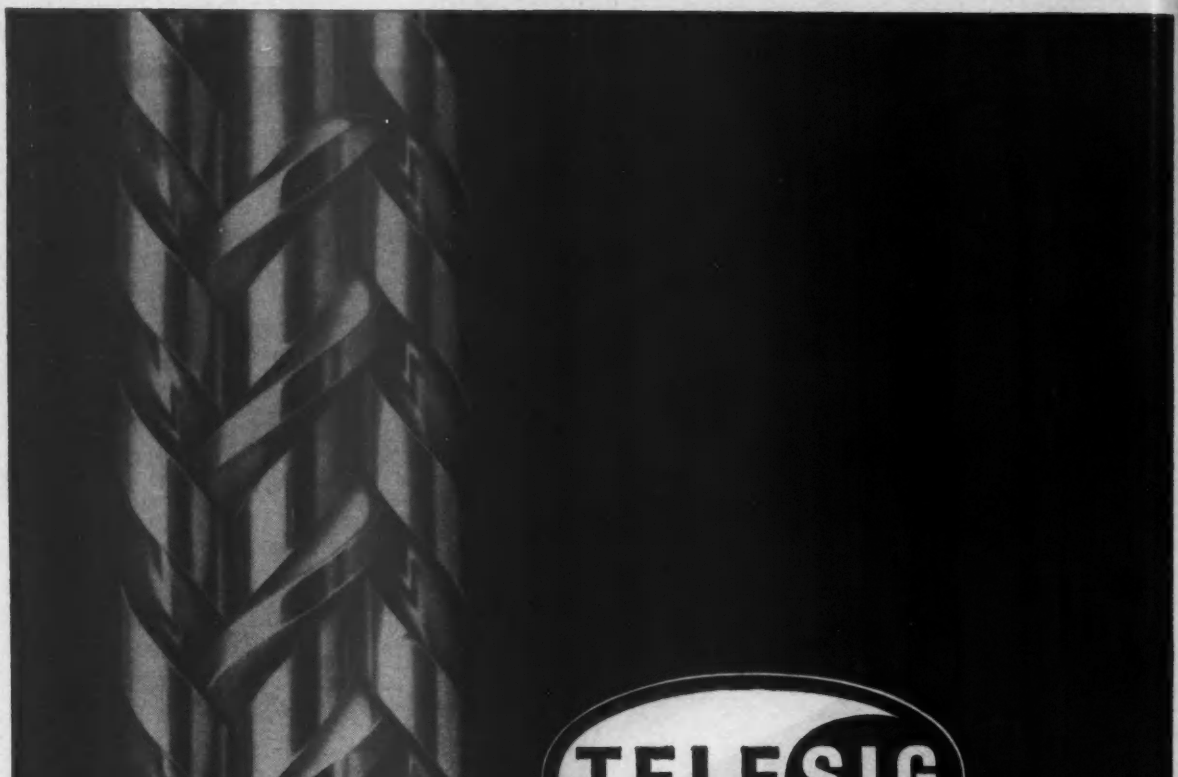


SCREW PUMPS

TELESIG Screw Pumps are positive displacement pumps. Simply constructed, they offer exceptional performance and long life. TELESIG pumps effect delivery by means of three parallel screws engaging each other, the power-driven central screw driving the two side screws. They may be run at high speed thereby reducing motor sizes and installation costs.

TELESIG Screw Pumps offer the following advantages:

- Self priming.
- Delivery free from pressure pulsation.
- High working speed — small size.
- Near-silent operation.
- Simple construction.
- Minimum maintenance and easy replacement of working parts.
- Long life.

TELESIG Screw Pumps are made in three basic ranges: for low pressures up to 300 psi, for medium pressure up to 1000 psi and for high pressures up to 2,500 psi. 42 sizes are available covering a wide range of capacities.

TELESIG

Screw Pumps by Telehoist

TELESIG pumps and equipment are made by Telehoist under licence from the Swiss Industrial Company (SIG).

Telehoist Limited. Cheltenham England. Telephone: Cheltenham 53254

an associate company of Wilmot Breeden Ltd.

Here is a 12v. stabilized d.c. supply at 4 amps!

How to obtain high current constant voltage D.C. supplies?

You could use cumbersome batteries, with their need for constant attention, but it is far simpler and certainly more reliable to use one of the new 'Advance' Constant Voltage D.C. Supply Units. This latest development in the application of Constant Voltage Transformers can be used to provide various d.c. supplies up to quite high current levels, as used in computers and data processing equipment. We shall be pleased to arrange for one of our technical representatives to call and discuss your requirements.

These new D.C. Supply Units . . . .

- **Provide HIGH CURRENT OUTPUT AT LOW COST**
- **Are SMALL IN SIZE AND WEIGHT FOR VA OUTPUT**
- **Have HIGH ENERGY RESERVOIR, thus are suitable for pulse, intermittent or variable loads**
- **Operate with HIGH EFFICIENCY**

TYPE	OUTPUT RATINGS		NETT PRICE IN U.K.
DC.1	6 volts	1.25 amps	£20
DC.2	6 volts	4.00 amps	£25
DC.3	12 volts	1.25 amps	£20
DC.4	12 volts	4.00 amps	£27
DC.5	24 volts	1.00 amp	£20
DC.6	24 volts	5.00 amps	£30
DC.7	48 volts	1.00 amp	£20
DC.8	48 volts	4.00 amps	£35

Advance CONSTANT VOLTAGE

INTERKAMA

D.C. POWER SUPPLIES

STAND No. B2025/6/D

Full technical details available in leaflet GB.101

Advance COMPONENTS LIMITED

MAINS STABILIZATION DIVISION

ROEBUCK ROAD • HAINAULT • ILFORD • ESSEX • TELEPHONE : HAINAULT 4444

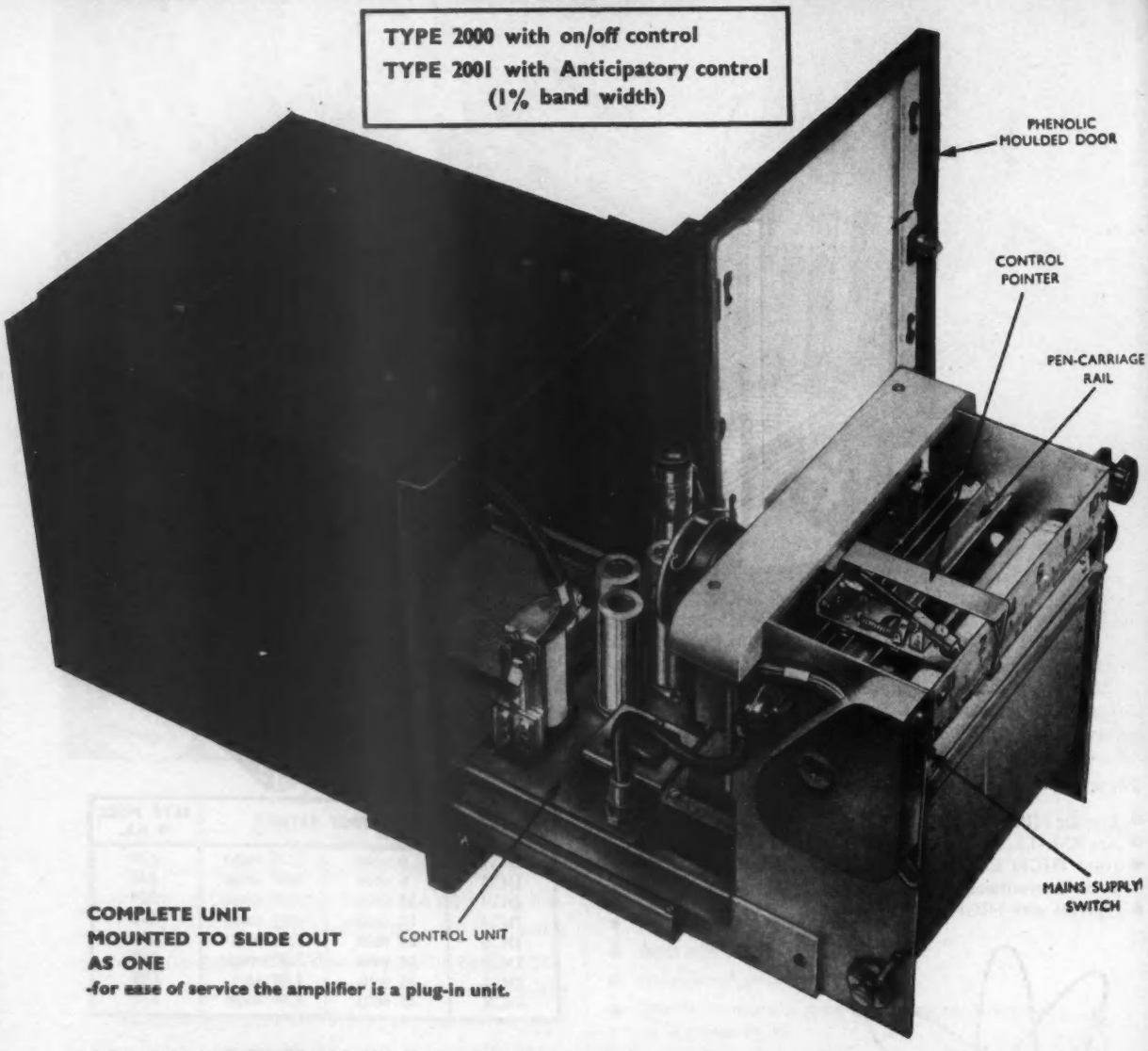
IT/.D 77

ETHER 'XACTROL pro

LIMITED

Potentiometer Recording Controllers, SERIES 200

TYPE 2000 with on/off control
TYPE 2001 with Anticipatory control
(1% band width)



COMPLETE UNIT MOUNTED TO SLIDE OUT AS ONE
-for ease of service the amplifier is a plug-in unit.

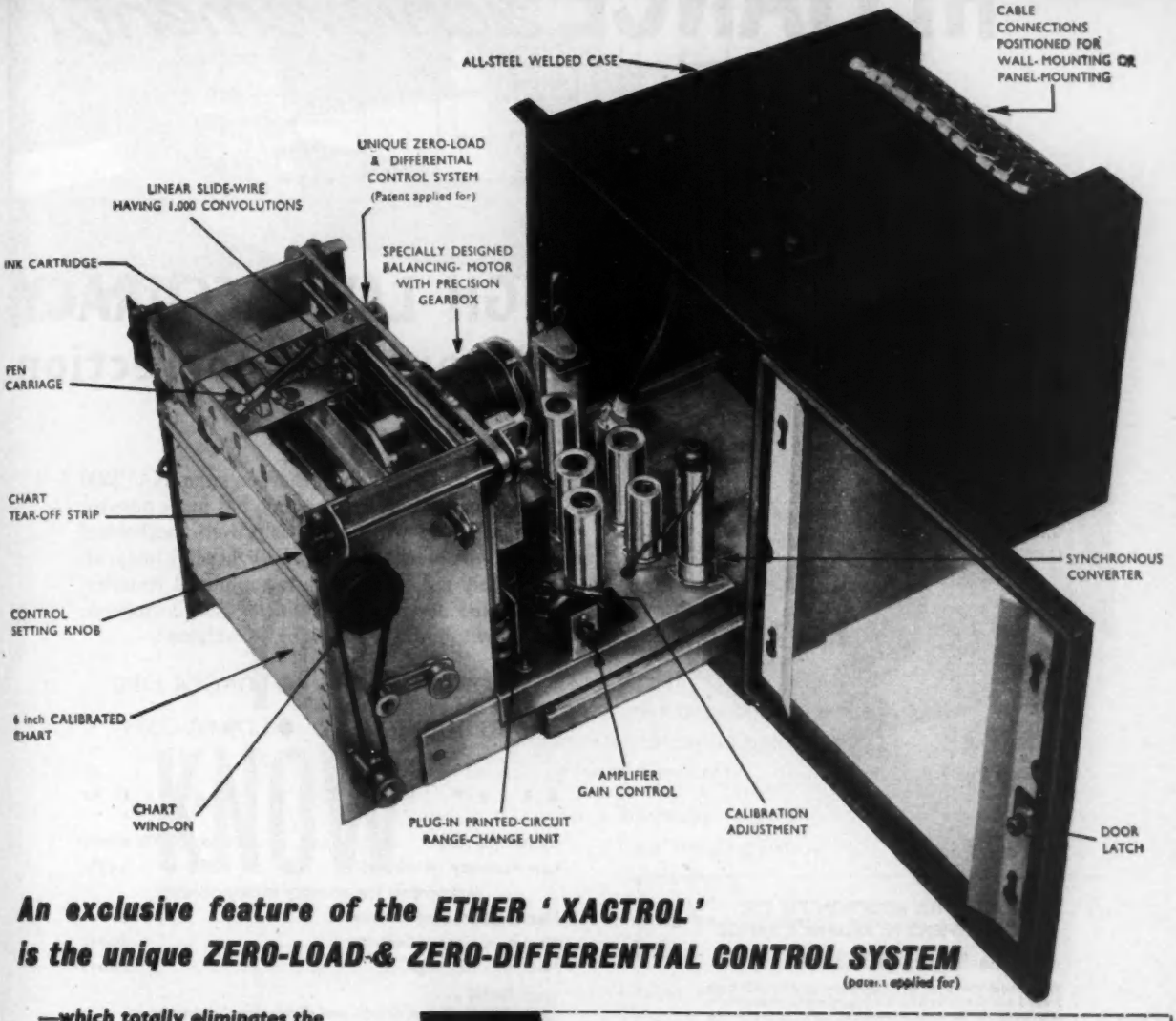
ETHER 'XACTROL' Potentiometer Recording Controllers are high-quality instruments, of the very latest design, for accurately controlling and measuring temperatures of — 200°C up to + 2,000°C. They are equally suitable for measuring variables such as speed, strain, pressure and hydrogen-ion concentration, as well as any other quantity that can be expressed as an electrical signal.

Circle No 57 on reply card for further details

* SIMPLICITY OF DESIGN * EASIER RANGE CHANGIN

provide EVEN HIGHER STANDARDS OF PERFORMANCE

SALIENT FEATURES INCLUDE! * Unique Zero-load & Zero-differential control system * 6" calibrated scale * Small panel cut-out 10½" 9½" * Patent Ink Cartridge * Front control-point setting



An exclusive feature of the ETHER 'XACTROL' is the unique ZERO-LOAD & ZERO-DIFFERENTIAL CONTROL SYSTEM (patent applied for)

—which totally eliminates the use of mechanically-operated linkages and snap-action switches

- **ZERO-LOAD even at control point**
- **ZERO-DIFFERENTIAL**
- **WIPING-ACTION, continuously-cleaning contacts**
- **ADJUSTABLE OVER FULL SPAN**

from £125-0-0 delivered

FILL IN AND POST NOW

Please supply, without obligation, full details of the ETHER 'XACTROL.'

C.9

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ADDRESS .....

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Attention of .....

ETHER (REGD.)

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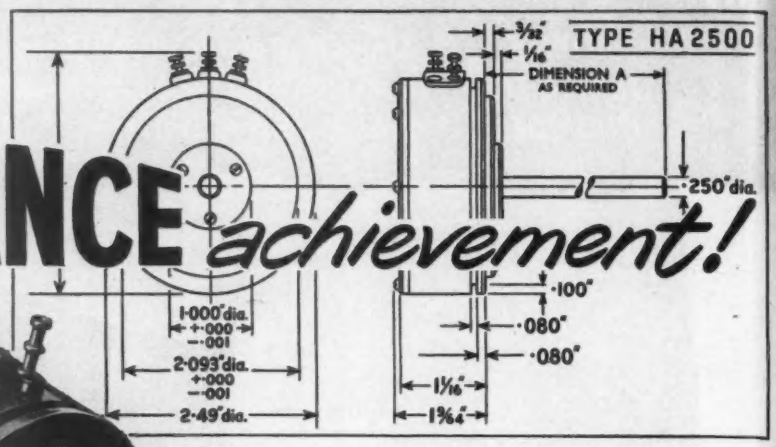
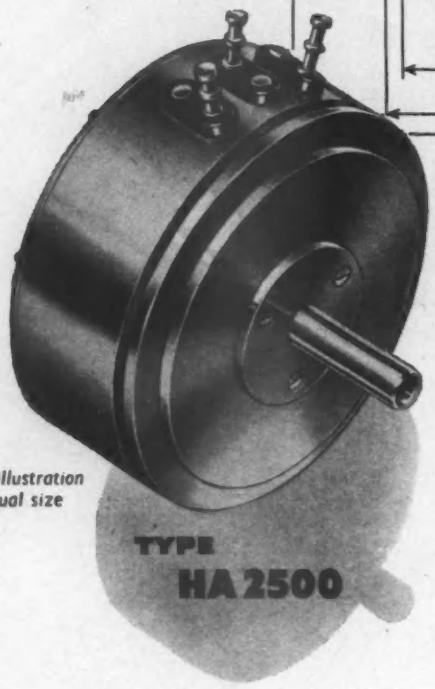
*GREATER ACCESSIBILITY * EASIER SERVICING & INSPECTION*

a new RELIANCE achievement!





This illustration is actual size

HIGH LAW ACCURACY
without cam correction

In this new continuous rotation type HA 2500 Potentiometer intensive research has made possible high accuracy with much improved mechanical stability. A precision machined light alloy body, an accurately ground ball-bearing mounted spindle – a patented design that eliminates cam correction, combine to give the following advantages :—

- LOWER TORQUE
- LONGER LIFE
- REDUCED WEAR
- LOWER COST

BRIEF SPECIFICATION

Resistance range	100 to 100,000 ohms.
Law Accuracy (Absolute)	± 0.25% or ± 0.10%
(Independent law accuracy to closer limits)	
Maximum Starting Torque	1 oz/in.
Maximum Ganged Sections	Four.
Maximum Tappings	Nine.

Full technical details and dimensional drawings in Data Sheet No. 100 available on request.

●

If our standard types do not meet your particular requirements, our research and development engineers are at your service.

RELIANCE MANUFACTURING CO. (SOUTHWARK) LTD.
SUTHERLAND ROAD · HIGHAM HILL · WALTHAMSTOW · LONDON · E.17.
Telephone No. (and for Cables) LARkswood 1118/9

. . . and ANOTHER ADDITION TO THE COMPREHENSIVE RELIANCE RANGE

The TYPE W3 (3 WATT)

This model conforms with specification DEF-5121 style RVW 7 & 8 (formerly RAC.RAD) and is a fully sealed unit with integrally constructed moulded cover. Also available in unsealed version.

Full technical details in Data Sheet No. 9

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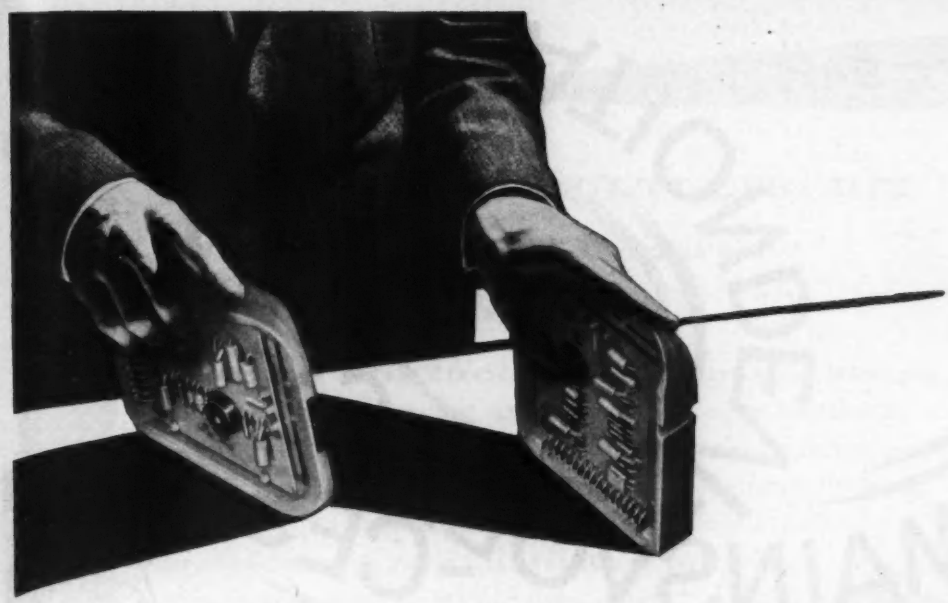
GD.60



DO YOU KNOW

...that 'Datapacs' are a range of transistorised logical elements from which control systems can be built up for all forms of

Telemetry
Data Handling and
Data Logging

...that these systems can be extended or modified to meet requirements

...that easy maintenance, minimum equipment and reliability are inherent features provided by these units

'ENGLISH ELECTRIC'

data processing

The ENGLISH ELECTRIC Company Ltd.,
Marconi House, Strand, London, W.C.2
Data Processing and Control Systems Division,
Kidsgrove, Stoke-on-Trent, Staffs.
Telephone: Kidsgrove 2141/3

EDC. 27

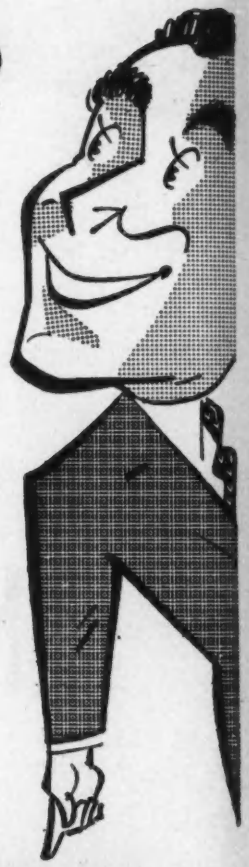
Circle No 60 on reply card for further details

DON'T SAY...

MAINS VOLTAGE DEVIATIONS

STABILIZATION

...SAY **VOLSTAT**



VOLSTAT is the one simple word you need to remember when you are up against any mains voltage fluctuation problem.

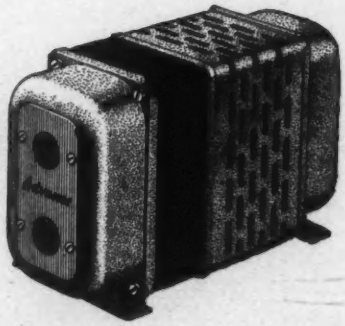
VOLSTAT stands for a range of Constant Voltage Transformers produced by 'Advance'— the leading authority on voltage stabilization.

VOLSTAT is backed by exclusive design, development and manufacturing skills which over many years have so often provided the only solution to mains voltage stabilization problems.

INTERKAMA

STAND No.
B/2025/6/D

Full details in Folder GM1 available on request.



Advance COMPONENTS LIMITED

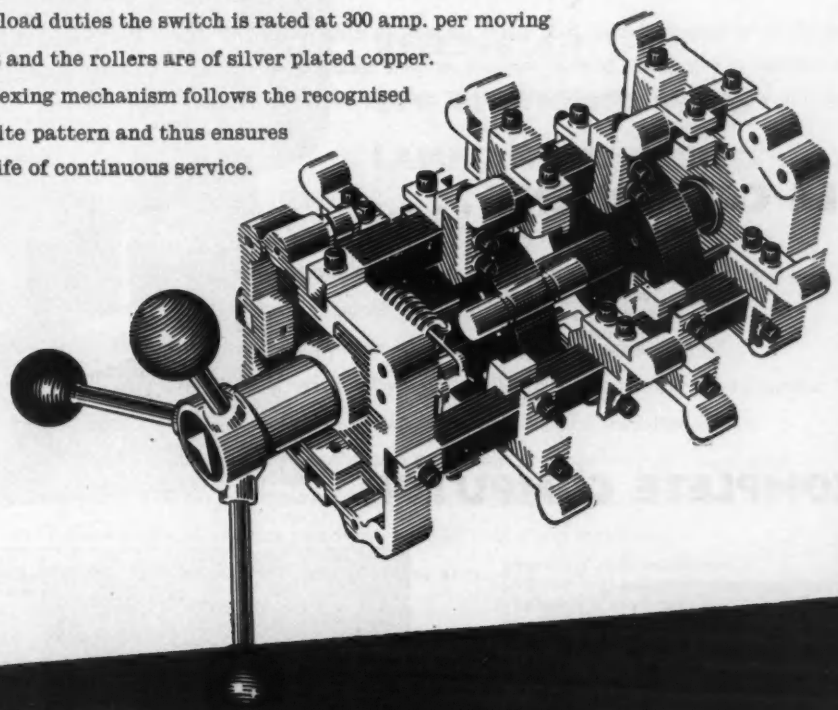
MAINS STABILIZATION DIVISION — ROEBUCK ROAD · HAINAULT · ILFORD · ESSEX · HAINAULT 4444

IT/G.D.82

The A150

—HEAVY DUTY MULTI-CIRCUIT A.C. SWITCH 150 amperes at 650 volts on each moving contact

This is a slow-make-and-break On-Load switch but is, of course, equally suitable for Off-Load duties. Its design is essentially similar to that of the other Austinlite rotaries. The moving contacts are rollers bridging pairs of fixed contacts. For on-load switching the rollers are Elkonite. The fixed contacts have silver contact faces $\frac{1}{32}$" thick. For off-load duties the switch is rated at 300 amp. per moving contact and the rollers are of silver plated copper. The indexing mechanism follows the recognised Austinlite pattern and thus ensures a long life of continuous service.



- Contacts are open to immediate visual inspection and the switching sequence can be seen at a glance.
- Each group of fixed contacts is mounted on a common bar which can be removed for cleaning or for replacing contacts.
- An A50, A30 or an A15 switch can be mounted in tandem for switching auxiliary circuits.
- Fixed contacts can be mounted anywhere on the bar so that creep distances can be increased and high voltage switching made possible.
- Mechanical interlocking can be provided.

A quick-make-and-break D.C. version of this switch, identical except for the indexing mechanism, will be available shortly.

Austinlite

ROTARY SWITCHES

Custom-Built by

STONE-CHANCE LTD.

(Makers of Sumo Pumps and Stone-Chance Lighthouses). Crawley, Sussex.

DELICATE CARGOES

travel better with Hairlok

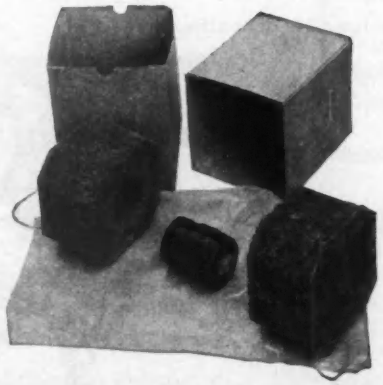
Modern electronic equipment is too delicate to face even normal travel hazards. Unless it is scientifically packed and cushioned many thousands of pounds worth of work and effort can be rendered useless.

The Hairlok Laboratories have every facility for studying, planning, designing, testing and constructing every form of special packaging using Hairlok as a basic cushioning material specially moulded to firmly hold and protect your product.

Hairlok is the finest rubberised hair, and is the most suitable material for electronic packaging purposes. It can be moulded in any density to meet the most stringent specifications and can be combined with individually constructed outers to withstand the rigours of all forms of handling and transit.

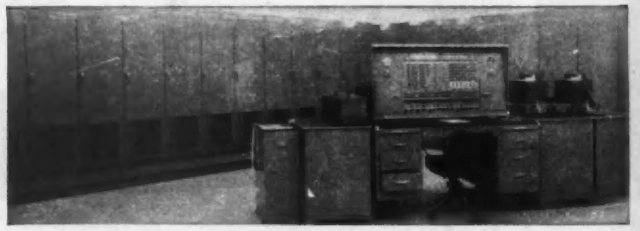
SINGLE COMPONENT . . .

Simple HAIRLOK cushioning for an expensive item of equipment with its tailor-made box.



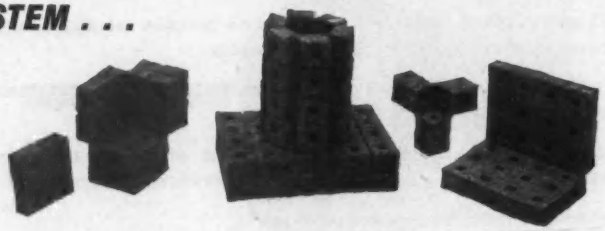
TO COMPLETE COMPUTOR

Complicated data-processing equipment like this National Elliott System has been successfully packed with HAIRLOK for transportation to the other side of the world.



THE ECONOMICAL ATLAS SYSTEM . . .

. . . consists of a range of standard modules or units which can be combined in many simple ways to protect a variety of shapes and sizes. Some of the modules and the shapes that can be accommodated are shown here.



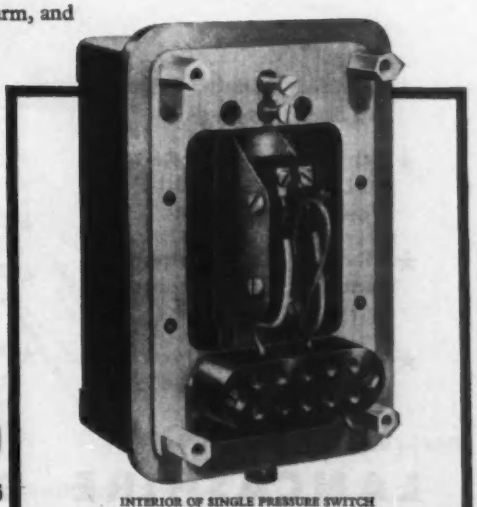
For literature and further details, write or phone :

THE Hairlok COMPANY LTD. Magna Works, Kathie Road, Bedford. Tel. Bedford 4271

KEEPING AN EYE ON THINGS WITH LAMP ANNUNCIATORS

There is a range of Firth Cleveland lamp annunciators to keep an eye on things for you. These are designed for alarm and advisory functions wherever visual signals are required. Where you need the additional protection of an audible signal, we can arrange a bell, hooter or siren to be connected in parallel. A muting switch allows you to silence the signal once your attention has been attracted, and when conditions return to normal there is an automatic reminder for you to reset it. We have designed the case so that you can mount it to suit yourself—semi-flush or projecting from the panel. You can use these annunciators in conjunction with the Firth Cleveland capsule operated pressure switches for liquid level alarm indication.

Single switch units are available for high or low alarm, and double switch units where dual protection is required.



INTERIOR OF SINGLE PRESSURE SWITCH

The range of Firth Cleveland industrial instruments also includes Hydrostatic tank contents gauges and pressure relief valves all of which are complementary to each other. We shall be happy to send you full details.

FIRTH CLEVELAND INSTRUMENTS LTD

Stornoway House, Cleveland Row, London, S.W.1. Telephone WHitehall 2166

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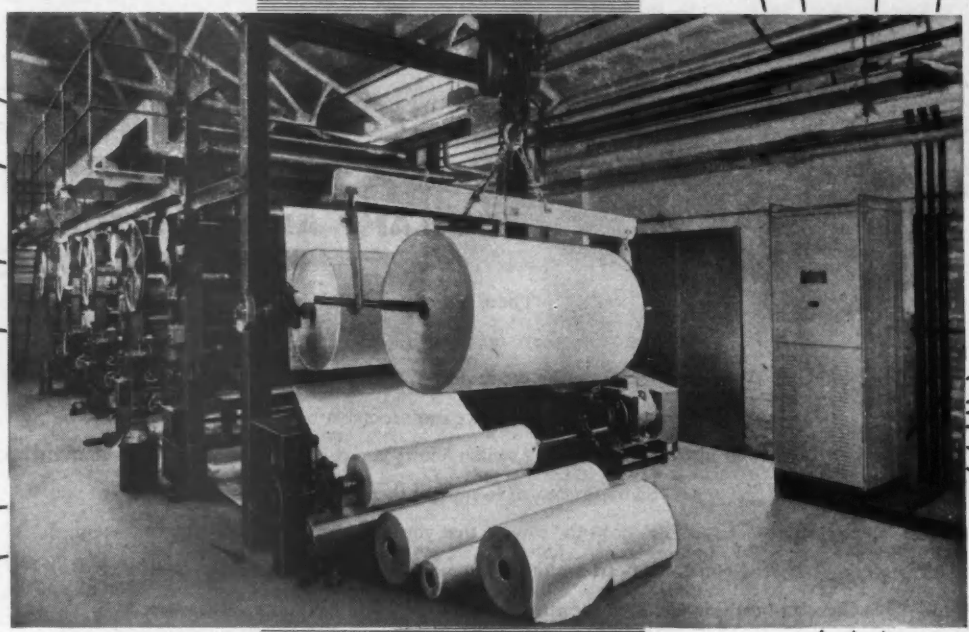
A MEMBER OF THE FIRTH CLEVELAND GROUP

CRC 310

VARIMAG MAGNETIC AMPLIFIER
Variable Speed Drives



20 h.p. Varimag Drive installed on a proofing machine

★ Infinitely Variable Finger-tip Speed Control

★ Standard Speed Range 20-1 or up to 150-1 for Special Applications

★ Manual or automatic, local or remote control of speed

★ Any Type of Motor Enclosure

★ Single or multi-motor drives

★ No external starting equipment required

★ No valves—no warming up time

Write for technical leaflet NV390

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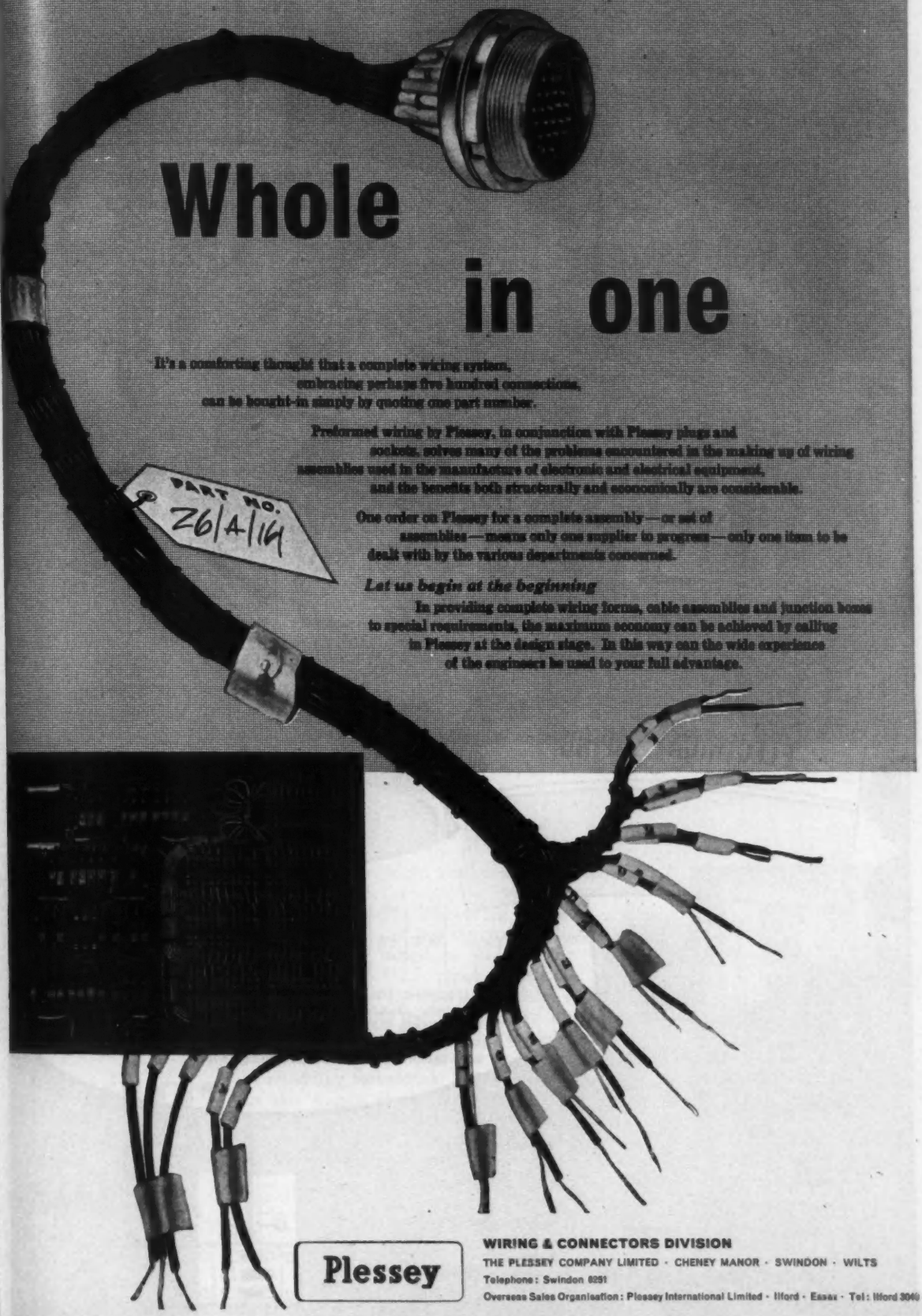

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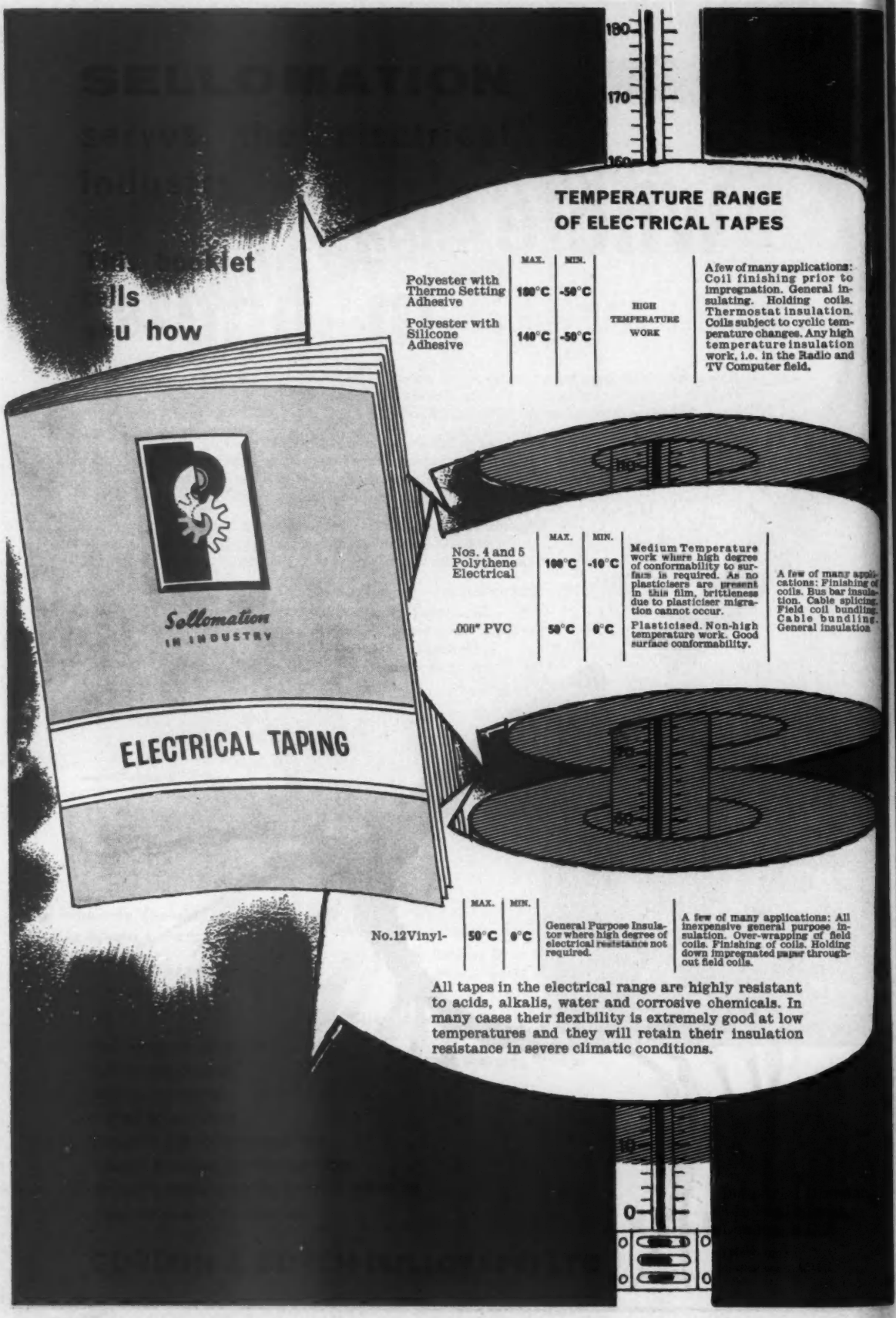
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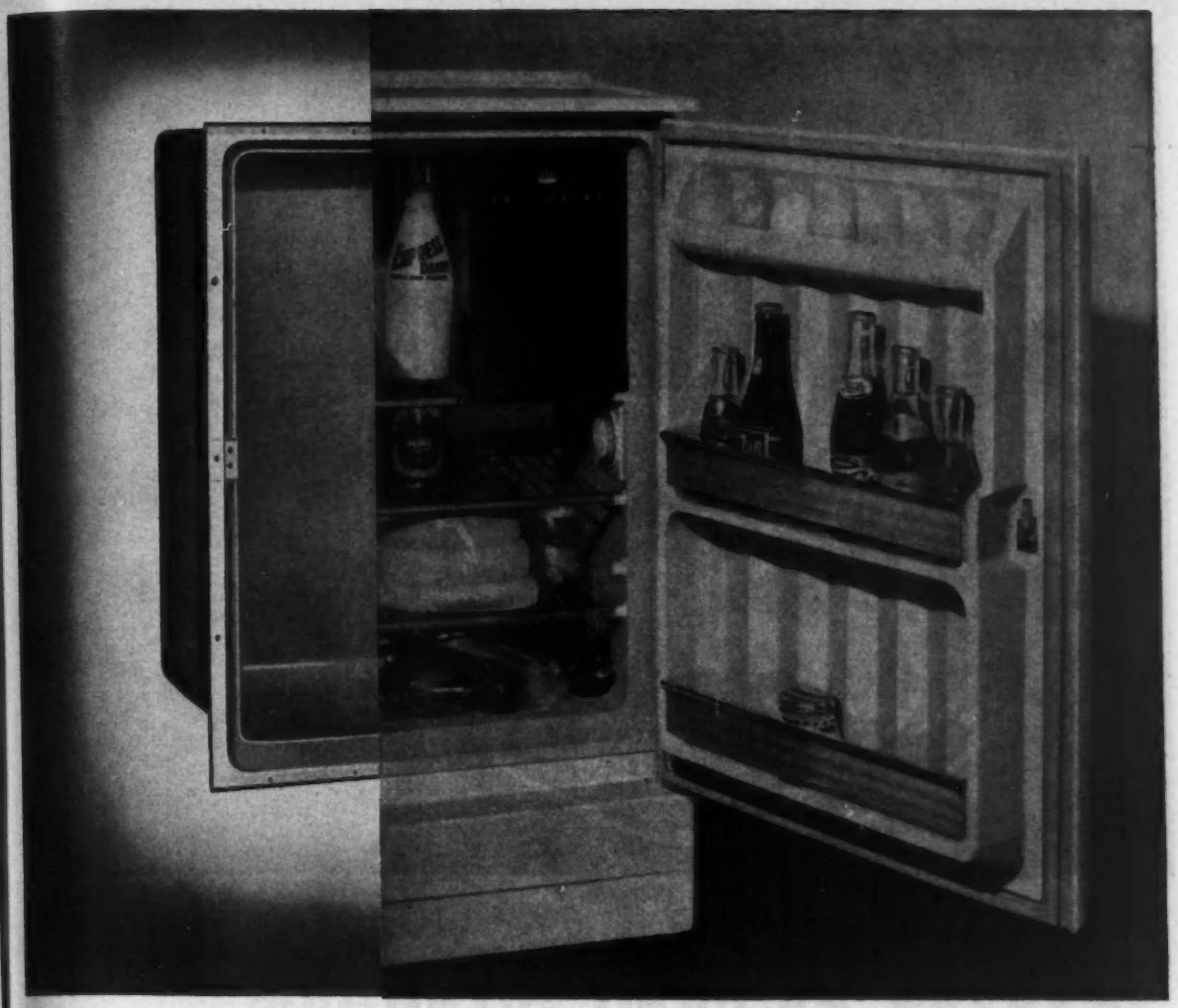

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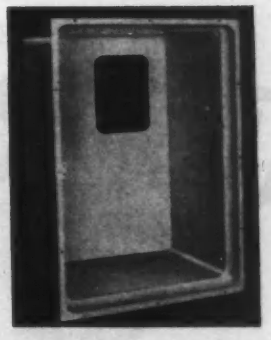

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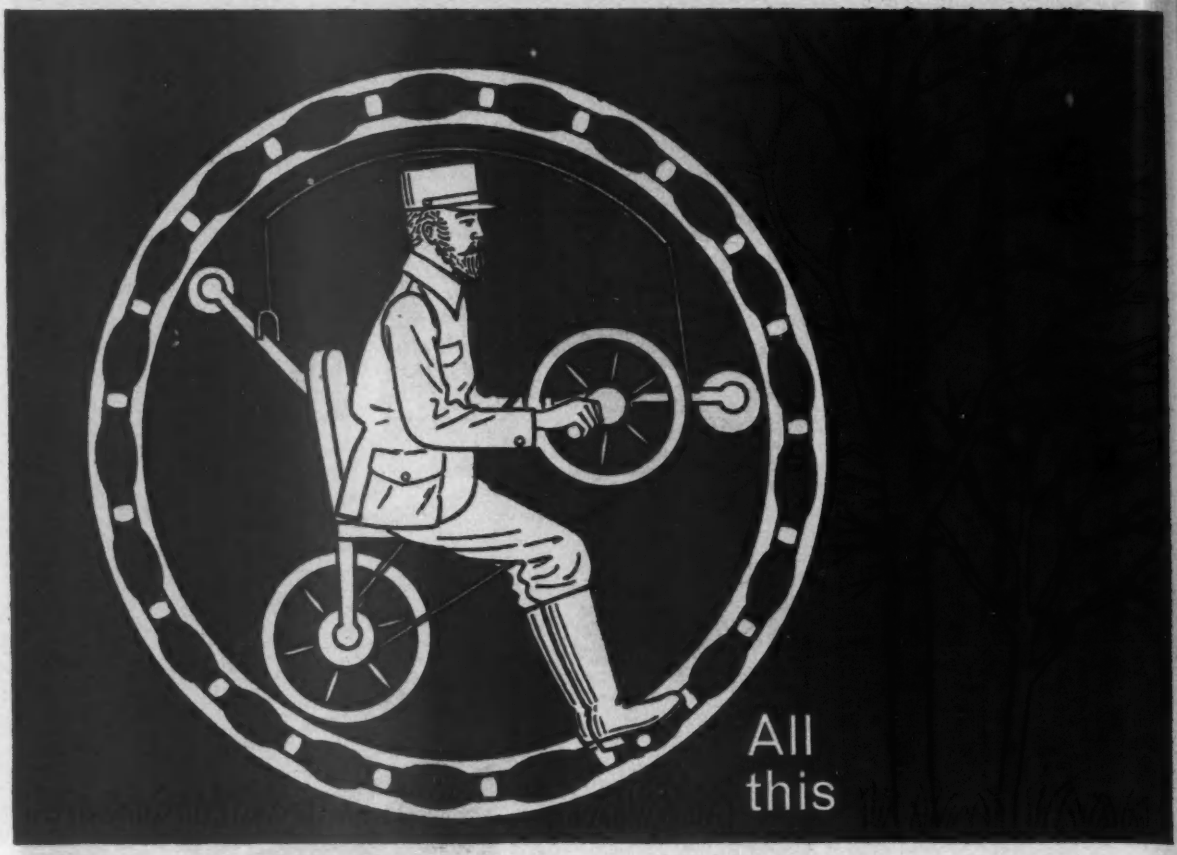

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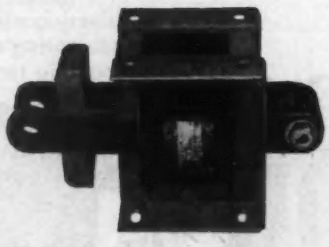

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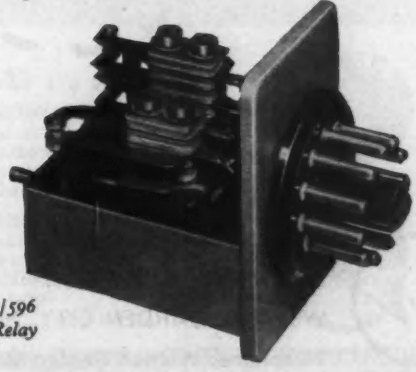

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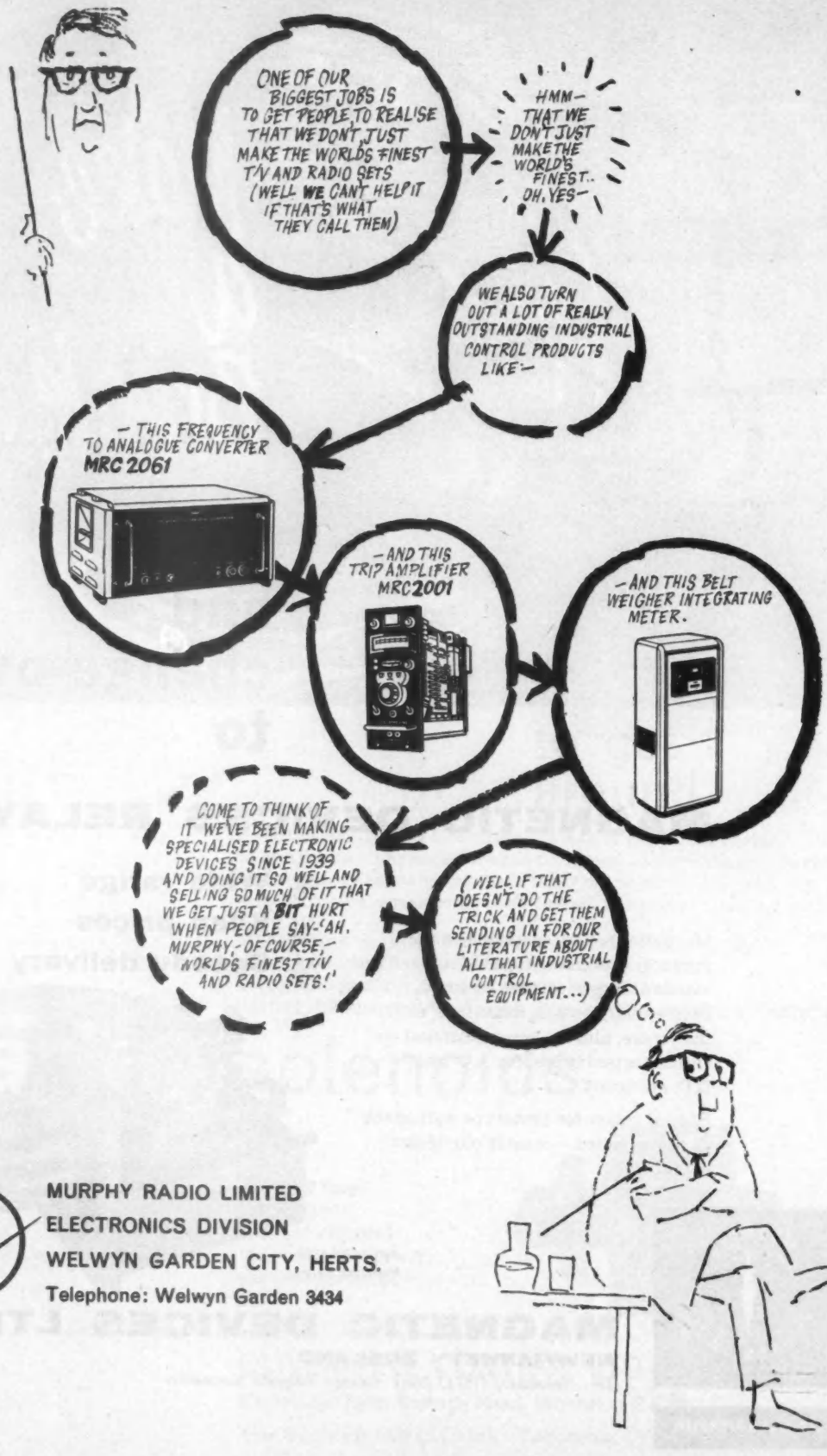
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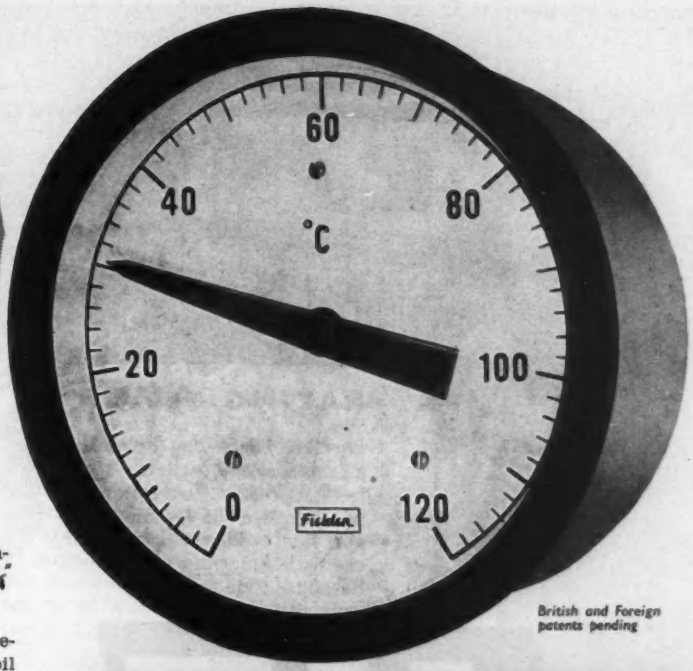

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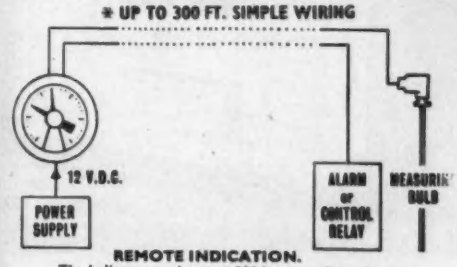

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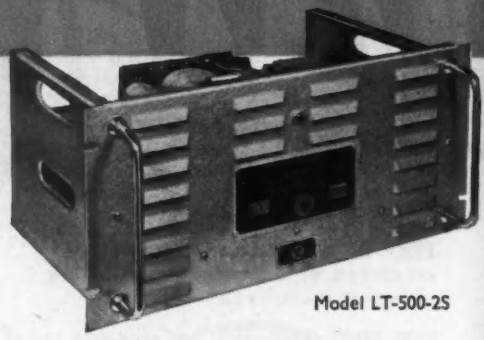

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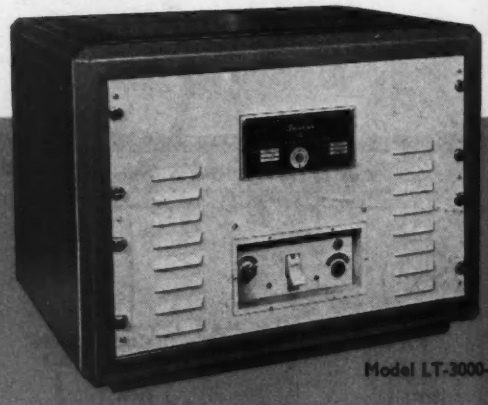

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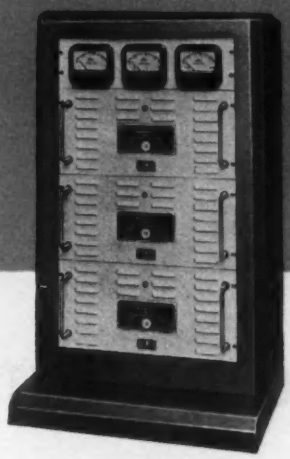

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The response time of 0·3 sec. is negligible compared with motor control regulation systems.

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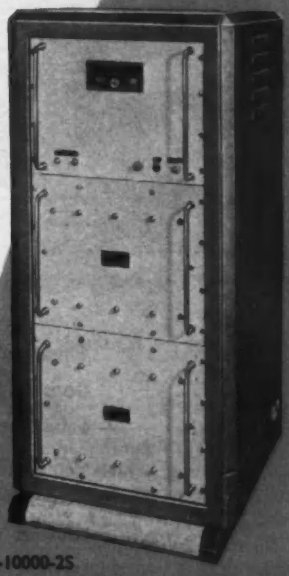

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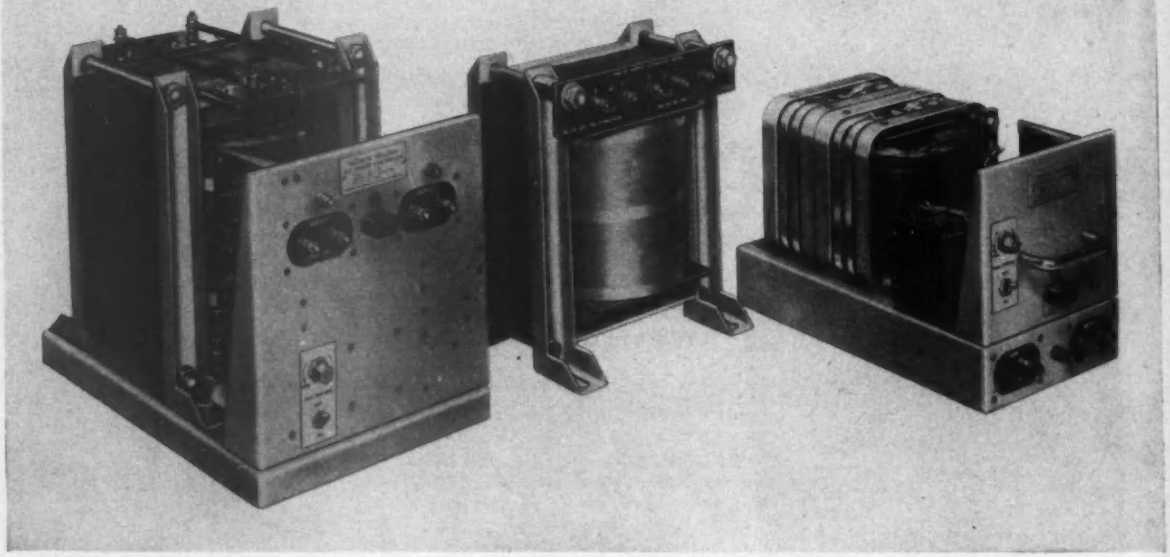

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The data sheet on the OC35 gives detailed information to ensure satisfactory operation of the transistor in as many industrial circuits as possible. So if you are looking for a general purpose *power* transistor for new equipment design, save yourself time by posting the coupon below.

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V_{ce} max. (I_c = 6A)	-32V
I_c max.	6.0A
p_{tot} max. (at mounting base temperature 45°C)	30W
T_j max. (continuous operation)	90°C
T_j max. (intermittent operation 200 hours max.)	100°C
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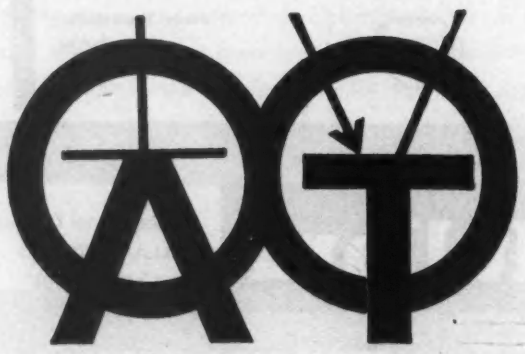

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SEPTEMBER 1960 VOL. 3 NO. 27 CONTROL

Community and establishment

JUST OVER A YEAR AGO, in *Control* for September 1959,* Christopher Rivington wrote his last leader before moving on from the Editorship of this journal. He chose as his subject what he called the 'society tangle', the 'plethora of professional bodies' that claim the attention of the young control engineer, and stated the reasons that justify the existence of professional societies generally. He then inferred that a professional society is necessary for control engineers, and proceeded to examine how the need might be met. Now, more than a twelvemonth later, one can read that leader again and find it as fresh and topical as when it was written. This is a sad commentary on the somnolence that still snores on in certain places.

David Foster, contributing to our July issue,† rightly felt it important to point out again that automation is a horizontal technology, with the same significance as mechanical, electrical, chemical and communications engineering. Putting four arguments, all showing that proper representation for control engineers is a crying need, he tilted at the complacency that is holding back automation in this country.

In *Control* last month,‡ J. H. Westcott told us how seriously the subject of automatic control is taken by Americans and Russians. In Britain, he remarked, people 'still seem sometimes to be a little bit in doubt about it'. In other words, responsible men in this country are slow in recognizing and taking up the art.

The three personal viewpoints that we have just quoted are, we believe, typical of the present sense of informed opinion. This opinion is not often expressed very loudly, because control engineers are always busy and often diffident. But let the fact be faced, we live in a world of pressure groups. There is a danger that unless control engineers combine to make their professional presence felt, neither Government nor Management will be moved to notice their case, let alone the importance of their existence as a group. From what we have heard, it is nearly always an 'instrument' engineer who presses for the introduction of new control techniques in process industry (if only to get a little practical experience), while managers and senior engineers remain woodenly sceptical. Only when they are trying to push plant output beyond its designed value do those cautious captains show interest or initiative, and even then they think first in terms of bettering materials or availability rather than of improving dynamic performance.

'Is there really anything in all that abstruse mathematical analysis? Has control engineering any real future? Those are questions you will still find asked here by influential people': thus Westcott in *Control* last month. For an answer he prescribed a fortnight's reading of the Ifac Congress* proceedings, but who will look at them except those already converted and well versed in the art? The congress itself caused scarcely a flicker of interest at home. Perhaps this indifference was not altogether remarkable in the popular press: the magic word 'automation' has become rather old-fashioned; reporters may have been a little shy about the smallness of the British contribution; and anyway, unless the general public can fasten on to an easily grasped achievement—like a few tons of ironmongery whirling round the moon—it becomes both bewildered and bored; as also (one fears) do the politicians. Hence presumably the lack of interest in the lay press, but why has the congress been so little noticed in technical journals? At least partly because too many well-settled engineers — and therefore the papers that specially serve them — do not care much for what they regard as an unreal subject.

Control has already given a good deal of publicity to a forthcoming symposium in London, where the Ifac Congress is to be reported and discussed.‡ We join Westcott in advising everybody who is not sure that the subject exists to go to that symposium, to hear what the British delegates have to say, and to fire questions at them. Maybe it is also permissible to hope that there will come out of that meeting a reborn and magnified B.C.A.C.: or, if we cannot have that, then a movement to create a body truly representative of British control engineers. For they are men who must have both organized community and professional establishment if they are to influence the powers in the land.

* Page 79. † Page 83. ‡ Page 87.

* Fully reported in *Control:* July, pp. 84-87; August, pp. 84-96; this month, pp. 92-98.

‡ London, 27-28 September. Details from Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

LETTERS to the EDITOR

Appeal to the user

SIR: In his 'Thoughts on the I.E.A. Show' in your June issue, your contributor L. Landon Goodman comments that, while there were many 'building bricks' on show, there were insufficient samples of complete systems. I fully agree with this statement and the Systems Engineering Group of my company are already working to correct this situation. This was, I hope, shown by the display of our process control computer Anatrol, as the main element of a gas flow blending *system*.

Our group has been at work for just over twelve months and Anatrol is the first of a range of major units intended to link input units to control units in comprehensive automatic systems. Work is also under way on a number of application studies and the main problem which we now face, in this new activity, is the identification and understanding of the problems of the industries we wish to serve. It is not a simple problem however, for while we usually find that the engineers responsible for instrumentation and control are thinking very much along the same lines as ourselves, there is a general educational period ahead before the ideas and techniques become sufficiently proven to be accepted, even to the extent of the process industries conducting really significant trials on which to base their future plans.

We and I know that others, convinced that Automation Systems can result in major economic advantages in the operation of many processes, are ready to make facilities available for field trials and I hope that those who are interested, in the user industries, will make opportunties to enable this work to go ahead.

De Havilland Propellers Ltd R. A. RUBINSTEIN

From a cybernetous man

SIR: I regret that I still cannot accept Mr. Beer's contentions*.

Of course all differences of degree, even slight ones, are important, but if we are going to set a dividing point at which we use a new term to describe a control system of a certain degree of sophistication, then as men of scientific minds we must define that point with some precision. Having done that, we may coin a new descriptive-word for systems of the more advanced degree, but we should not misuse a word which is already broader in meaning to describe a narrower field. A near parallel of what Mr. Beer is doing would be to use the word "cerebral" in describing a man's brain, in order to indicate its degree of difference from that of a monkey. Clearly this is absurd, as "cerebral" describes both.

As to the grammar, "model" exists both as a noun and an adjective. If we must have an adjective derived from "cybernetics", should it not be "cybernetical" or "cybernetous"?

The science of cybernetics is employed, unconsciously most of the time, in the control of every company. Similarly, a dentist whose feet bear his weight all day, because he takes care of his bunions, is applying some of the science of orthopaedics, but it would be misleading to describe him as an "orthopaedic surgeon."

Of course, I am no grammarian but a mere pediatric man, so I may be putting my foot in it here. I hope that as a biochemical, neurological, psychological, cybernetic man I shall prove sufficiently self-adaptive to my environment to survive any reaction!

JOHN B. RUDKIN

Bishop's Stortford, Herts

* 'Letters' last month, p. 80.—EDITOR

Two points of view

SIR: As I see it, the purpose of a technical journal is to inform the practising engineer of new design methods, new equipment, and any new trends that may have escaped his notice. More and more, however, do I read in journals like yours the general opinions on semi-technical and non-technical matters of, presumably, editorial staff.

For example, in your July issue 'Uncontrolled' discussed the British Association's report on the pros and cons of the metric system. Reasonable enough: but why conclude that the Government has neither the knowledge nor the ability to evaluate and legislate on the informed advice which the various interested parties must have provided it with?

Another example in the same issue: 'Staffman', who writes your personalities page, mentioned Dr. D. Taylor's appearance before the Parliamentary and Scientific Committee, and his 'championship of the space cause'. This is not a subject for levity, as this country will learn to its cost if we continue to think of rockets in terms of science fiction. The satellite exists, and there is no practical reason why it should not revolutionize world communications.

To reiterate: the duty of a technical journal is to inform on matters technical and not to indulge in half-baked witticisms.

Worcester J. H. SNOW

SIR: I should like to congratulate you upon your superb review of the I.F.A.C. Conference in your August issue. 'Control' has a remarkable flair for making palatable as well as comprehensible what might otherwise be as dry as the proverbial dust. This goes for the whole of your excellent magazine.

Manchester R. N. FELTON

PUBLISHER'S COLUMN

Another first

In the next few weeks, Control's *first Industry Guide and Digest number will be published. This will incorporate the enlarged* Control *Buyer's Guide — the number of companies reviewed will be up by more than 25%.*

During our research for this special issue we found that only a comparatively small fraction of British control equipment finds its way oversea. We hope that, by high-lighting the new equipment and new ideas of this year, and drawing users' attention to the benefits of up-to-date control, we will play at least a small part in establishing the industry in new markets.

To provide an effective service in support of the new Industry Guide and Digest number, we have established an extensive industrial research section. This is freely available to all readers of Control *whenever they are seeking new equipment or ideas.*

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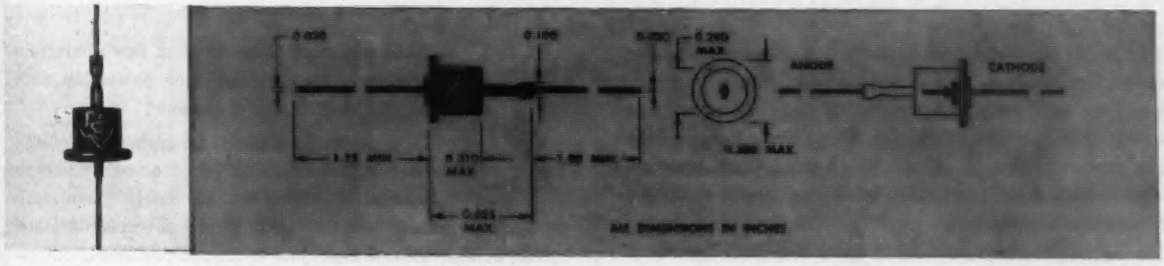
Single Current, 1 cycle at 60 c/s at +25°C	... I_{pk}	15	15	15	15	A
Operating Temperature, Ambient	... T_{amb}	——		−40 to +100	——	°C



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VIEWPOINT

This month the British aircraft industry goes on show at the annual Farnborough Air Display. Sir Roy Dobson, Vice Chairman and Managing Director of the Hawker Siddeley Group, suggests this is where to look for . . .

LEADERSHIP IN AUTOMATION

Automation, as a great many industrialists now realize, is the new industrial revolution which must come, and come quickly, if Britain's economic progress is to be assured. But, as yet, only comparatively light breezes of this particular 'wind of change' ruffle the surface of British industry.

From where is the drive, the leadership, to come in this new revolution? I suggest from the aircraft industry, which for the last half-century has been in the forefront of technological development.

Automation is integration—the integration of the most modern techniques and skills with the traditional crafts developed over the ages. Pure automation—the completely automatic process or factory—can be successfully carried out only by a large enough organization.

But knowledge and facilities are of no use without the ability to apply them. A recent contributor to this column* referred to the gap between the 1980 thinking of the electronics industry and the 1910 thinking of the user industries. This gap can be bridged only by an organization whose thinking is broadly based and flexible; an organization familiar with sudden expansion and change; an organization led by men with vision yet of sound engineering tradition.

The aircraft industry fills this bill admirably. Ironically, it will never be able to introduce a very high degree of automation into many of its own production techniques, but it has been turning out a highly automated product for many years. Control system engineering has always been an integral part of aircraft engineering, and modern civil and military aircraft and missiles are examples of the most sophisticated control and intelligence systems ever devised by man. Missile engineering, for example, has opened up many new fields from which industry will reap great benefits.

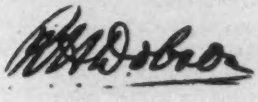
Electromechanical devices are still extensively used throughout industry for controlled switching, sequence controls, safety interlocking, etc. In missiles a more efficient, compact and reliable method was needed, and this led to the application of semiconductor physics. Now industrial companies in my own group have followed the lead of their associated aviation companies and successfully applied these solid-state devices to the control of heavy electrical equipment.

As a process becomes more completely understood, so it is easier to control. But to understand it one must collect and process a mass of data. Here the aircraft industry has developed instrumentation and telemetry which, for all practical purposes, is completely reliable. New methods of high-speed data handling and processing have revolutionized data analysis.

How many thousands of miles of recording paper and ink are wasted by industry every year on redundant information—in placing on record that a variable has, in fact, remained constant? The aircraft industry has for a long time found it necessary to record only relevant information and developed methods and equipment accordingly.

Environmental testing, whose use outside the military field is only just being appreciated, has been a feature of aircraft and missile testing for years.

So the list goes on. These are examples of the sort of new techniques which, allied with the traditional skills, is the basis of automation. Automation has to come soon and in a big way. The search for the necessary impetus need extend little further than this month's Farnborough Show.



*David Foster, Viewpoint, *Control*, July 1960.

Control at Farnborough

There is plenty to interest the control engineer at the S.B.A.C.'s 21st Flying Display and Exhibition, Farnborough, September 5-11

Much equipment at this year's Show has been developed for one or other, or both, of these two jet airliners. Above: the Vickers V.C.10; below: the DH121

SINCE THE LAST FLYING DISPLAY AND EXhibition at Farnborough, there have been many major changes in the make-up of the aircraft industry. At Government suggestion — one might say under Government pressure—various mergers occurred and the major part of the industry now consists of three major airframe and two major engine groups. These are: the British Aircraft Corporation, which consists of Vickers Armstrongs (Aircraft), English Electric Aviation, Bristol Aircraft and Hunting; the Hawker Siddeley Group, comprising the original members (Armstrong Whitworth, Avro, Gloster and Hawker), plus Folland, the de Havilland Enterprise and Blackburn; Westland Aircraft, comprising the original Westland helicopter interests plus those of Saunders Roe, Fairey Aviation and Bristol Aircraft; the two engine groups are Rolls-Royce, and Bristol Siddeley. Many familiar names are, therefore, less to be seen.

In aircraft engineering, perhaps the major breakthrough is in the field of vertical take-off aircraft. In particular, there are the Short SC-1 and the Bristol Siddeley BS.53 lift/thrust ducted-fan engine. A revolutionary feature of the latter is the use of moveable jet nozzles. Vertical take-off is studied in some detail by J. J. Foody on page 88ff of this issue.

The trend for aircraft concerns to enter the industrial automatic control field is growing rapidly, and many firms whose names are synonymous with the history of flight are showing quite down-to-earth devices. We understand that the electronics industry views this trend with mixed feelings: some fear — mistakenly we feel—that the aircraft industry's close ties with the Government may give the newcomers an advantage. However, the aircraft firms appear to be entering the field in strength. Hawker Siddeley's Sir Roy Dobson refers to this on page 83.

One of the more important problems of aircraft controls is reliability, and this aspect is highlighted by the competing automatic blind-landing systems being developed for the DH121 and V.C.10 jet airliners by Smiths (stands 1–4) and Elliott's (229–230), respectively. Smiths are working towards a triplex system—i.e. one composed of three independent subchannels working into a single controlling channel—to obtain the necessary high degree of reliability. Elliott's on the other hand, are developing a duplicated system in which both channels are separately monitored by what are, in effect, much simplified versions of the controlling channels. The competing claims for these two methods of obtaining a high degree of information redundancy are extremely interesting.

Flight control and navigation

The many firms in the electronics field showing ground and airborne navigational equipment are of particular control-engineering interest. The trend towards fully automatic landing brings the **autopilot** into yet greater prominence. Among their flight control equipment, Smiths Aviation Division (1–4) are showing the SEP2 (the current model) and also the new SEP4 which is part of the B.L.E.U. **Autoland** system. The latter at present comprises the Smiths autopilot and throttle control, Pye i.l.s., Murphy leader cable and S.T. & C. radio altimeter. However, if the new S.T. & C. i.l.s. is adopted, leader cables may no longer be necessary. This system is being installed by Bomber Command. Smiths' new multiplex SEP5 autopilot for the DH 121 jet airliner has reached an advanced stage of development. Their paravisual director, the barber's pole display discussed in our July issue, is much in evidence, as are their various integrated flight systems.

The **flight control system** for the V.C.10 jet aircraft is, of course, by Elliott Bros. (229 & 230) to Bendix designs. The Elliott/Bendix P.B. 20 equipment for the V.C.10 comprises two separate but identical transistorized systems each providing i.l.s. coupling with automatic throttle control, v.o.r. coupling, clutched and preset heading control, and height, airspeed and Mach number locks.

Honeywell Controls' (286) new **adaptive autopilot** is understood to adjust itself to changing flight conditions, e.g. in wind speed and height. A 'model' simulates the dynamics of an ideal vehicle and a controller brings the autopilot into line with this information.

A localizer transmitter and the new remote control unit of the S.T. & C. (146–149) **i.l.s.,** which is favoured by the Ministry of Aviation, is on view, as is their STR-40 **radio altimeter** for autolanding. The latter covers up to 500 ft only.

A 100,000-ft **servo altimeter** by Smiths (1–4) has a counter showing altitude to the nearest 50 ft, plus a pointer which makes one revolution for every 1000 ft. Movements, with height, of a pressure-sensitive capsule affect inductive pick-offs to provide signals for the indicators. The accuracy is ± 1 millibar. Kelvin Hughes (1–4) exhibit a servo altimeter covering − 1000 ft to + 70,000 ft. The accuracy at ground level is ± 20 ft, and at 50,000 ft ± 180 ft.

A great deal of navigational equipment is shown by Marconi's (11–15). Their modified AD 2300B **Doppler navigator,** an f.m.c.w. device, is shown. They claim to have overcome the 'height-hole' errors of which this type of Doppler has been accused. Operating at 8800

Mc/s, it comprises a sensor and computer giving speed and drift, miles to go, error, plan of next leg, and steering information for the pilot or autopilot. An associate, Canadian Marconi, show their **Doppler sensor,** Dagmar—drift and ground speed measuring radar.

Gyro instrumentation

Sperry (90) who are, of course, collaborating with Smiths and Kelvin Hughes in producing the instrumentation for the DH121, show the V.G. 202 **vertical gyro** which is intended for that aircraft among others. It is said to provide a precise pitch and roll reference. Sperry's Rotorace directional gyro, one of their Gyrosyn compasses, is exhibited. The **twin gyro platform** on show employs two Rotorace directional gyros and has a free drift rate of 0·25°/hour in azimuth. This platform is said to provide an attitude reference of inertial quality, without the need for liquid-supported gyros.

The **Gyrotwin reference** system by S. G. Brown (225) is half the size and weight, but twice the accuracy, of their master reference gyro, which it supersedes. The stabilizing and azimuth gyros are mounted in tandem and the servo amplifiers are fully transistorized. They also show the **Arma/Brown gyro,** a reference which may operate as either a North-seeking gyro or as a precision directional gyro. This has a 3-in. wheel floating in Fluorolube in a sealed sphere. The sphere is located by four ligaments, angular misalignment being detected by pick-offs. Signals from these are amplified and passed to servo-motors which control the angular position of the container and so cancel out the torsional strains on the ligaments.

Ferranti (176–177) have a **vertical reference gyro,** the FS. 16, designed to provide pitch and roll signals for attitude indication, etc. It incorporates synchros and toroidal potentiometers on both axes, and has gimbal freedom of 360° in roll and 85° in pitch. They also show a **standby artificial horizon** of the type used in Comet and future Boeing 707-436 aircraft; a similar system has been ordered by Argosy and Vanguard aircraft. Ferranti's **standby gyro system** comprises an artificial horizon, two directional indicators, a miniature direction gyro and an inverter unit.

Computation and data-handling

A **flight data system** by Kelvin Hughes (1–4) integrates flight and aerodynamic information for presentation on servo-operated displays. These respond to data from separate sensing, detecting and computing units. An aerodynamic computer accepts information from pitot, static and temperature sensors, and computes indicated airspeed and Mach number for presentation on the speed display. Altitude and vertical speed are computed and presented on a height display. Signals from a remote gyro are presented on the attitude indicator on a roller-blind display. The navigation display uses a roller-blind to present four modes: compass, i.l.s. deviation, Tacan, and homing. Kelvin Hughes also show an **electro-mechanical analogue computer** which measures pitot and static pressure to compute altitude, rate of climb, Mach, and air speed. Pitot and static pressures are measured by two force-balance systems, which accept the force output of a capsule to give a rotary output which is transmitted by cams and synchros to the presentation units. The force-balance outputs are fed to a servoed Wheatstone bridge to compute Mach number.

W. H. Sanders (Electronics) Ltd. (100) are showing a **logic system** having transductor sensing elements, together with an individual logic assembly. These are capable of operating with a memory to either store information or act upon fresh information at will.

A special divide-by-two **binary element** by McMichael (214) consists of a two-transistor bi-stable circuit which will operate at up to 100,000 counts/sec from 2-μsec pulses. It weighs ¼ oz.

Components from their Simlac and Simlac Minor **analogue computers** are shown by Short Brothers and Harland (59). Their new **control-system analyser** is also shown: this facilitates the investigation of feedback control-systems and components over the same frequency range as that of their low-frequency decade oscillator — 0·01 c/s to 110 c/s. Wayne Kerr's **transfer function computer** is shown on the stand of their principals, Wilmot Breeden (199).

An **aeronautical research computer,** an analogue machine for the solution of problems in aerodynamics, is exhibited by General Precision Systems (226). G.P.S. are also showing an **automatic radio aids unit** for the Link trainer.

Southern Instruments (153) have **trace reading equipment** for the digital analysis of analogue records. This consists of the trace reader and built-in decoder, initiating switch, and solenoid-operated electric typewriter.

Acorn—automatic check-out and recording equipment—which de Havilland Propellers (141) are showing, has been developed for testing complete systems in aircraft, missiles, and ground equipment. Channels are scanned and tested at the rate of one per second, and the results —the deviation of the measured parameters as decimal fractions of their permitted tolerances — are displayed and logged.

S.T. & C. (146–149) are showing the Strad **high-speed electronic switching** system, and Armstrong Aircraft (L) their **telemetry** and data-handling gear.

The new Apollo **digital computer** for air traffic control is displayed pictorially on Ferranti's stands (176–177). This is to go into experimental operation at the Scottish Air Traffic Control Centre, Redbrae, Prestwick, in the Spring.

Fuel and engine controls

Ultra Electronics (275), who are designing an **electric throttle-control** system for the Short SC 5 Britannic for R.A.F. Transport Command, are showing several examples of engine control equipment. These include the engine-mounted A605 **turbine-speed and jet-pipe temperature-control amplifier** for the Rolls-Royce Conway. Ultra's **engine-condition analyser,** a monitor of engine temperature and vibration, is also on view, as is their new **engine vibration indicator.**

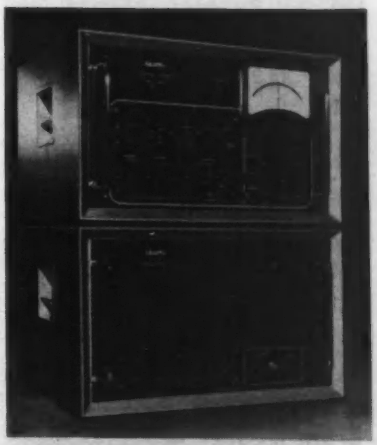
A full-scale mock-up of an **aircraft fuel-system** is shown by Armstrong Whitworth Equipment (L). Their fuel systems are used on such aircraft as the Lightning, Britannic, Fairey Gannet and FD 2, and the Gloucester Javelin.

Developed for the Rolls-Royce RB 141 and the RB 163 engines, Smiths' (1–4) **engine control systems** use magnetic amplifiers. Their fuel-control actuator is suitable for engine mounting, while the amplifier is for wing-root or fuselage mounting.

A fully-automatic **electrical fuel-control** for helicopters is shown by de Havilland Propellers (141). Developed for the Gnome engine, this relieves the pilot of all engine-handling; he merely selects the required rotor speed, and a computer maintains this throughout the flight. Their Pottermeter **flowmeter** is also on show.

The fuel-management systems for the V.C.10 are based upon the Elliott (229–230) **true-mass fuel-flowmeter,** a development of a Bendix design. The system

This Short control-system analyser indicates in-phase and quadrature components down to 0·01 c/s



consists of a true-mass flowmeter, with a computing circuit to indicate mass flow rate and fuel consumed. A synchronous motor drives an impeller at constant speed via a magnetic coupling to impart angular acceleration to the fuel; the force required to accelerate to a given angular velocity is a measure of true mass. This arrangement provides an electrical signal which is fed to a computer having an indicator which displays fuel consumed in digital form. Accuracy of flow-rate measurement is understood to be better than ± 1·5%.

A **four-channel mass-flowmeter** by Integral (166) is for measurement of fuel flow through four pipes on four-engined aircraft. Rotation of a helical rotor having a magnetic insert provides pulses which are computed to give total fuel consumed and rate-of-flow in mass units.

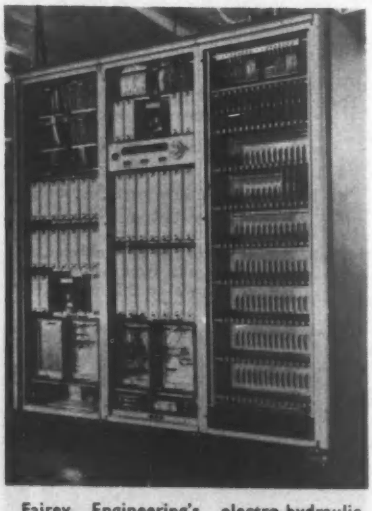
Negretti and Zambra (161) have their Series 2 **fuel flowmeter.** This depends on orifice measurement of flow, the orifice area being altered so as to maintain a constant pressure-difference. Any change in area is transmitted to an indicator calibrated linearly in terms of rate-of-flow or rate-of-flow plus fuel-consumed. Their **integrating indicator,** type I.R., is used in conjunction with a fuel flowmeter in the line to the engine.

A range of fuel equipment is exhibited by Simmonds Aerocessories and Firth Cleveland (180). The Pacitor **gauge for liquid oxygen** has been developed in co-operation with Normalair, and is based on the well-known type 2 Pacitor system. Various aircraft flowmeters (mass and volumetric) are shown. Their outside stand (S) has the Gilbarco/Firth Cleveland **electronic tank-contents gauge** and a **hydrostatic tank-contents gauge** of pressure-bulb type.

Waymouth Gauges, on Smiths' stand (1–4), are showing the type 4 transistorized **fuel contents gauge.** This utilizes a self-balancing bridge, and silicon transistors.

Sperry (90) are exhibiting a **vibration sensing and analysing system** for checking engine performance in flight or on the ground. Vibration pick-ups at critical points on each engine can operate warning devices, or indicate vibration levels.

Acorn, de Havilland Propellers automatic check-out and recording equipment for testing complex systems



Fairey Engineering's electro-hydraulic servo valve (below)

Air and temperature control

Cabin temperature control systems are a feature of Teddington Aircraft Controls' stand (41). Their simplified system is, in effect, a valve-positioning control, which enables the crew to select on a single dial any condition between full heating and full cooling. Their Ducstat **temperature sensors,** low-mass resistance elements, may be bridge-connected to form the basis of standard controllers, off-balance signals being amplified in transistorized units to switch control actuators. They also exhibit **outside-air-temperature elements, anti-icing** and **ice-warning equipment,** and wing and/or tail de-icing equipment. Several units for **missile heating control** are on show. In one of these, a small thermostatic valve, the complete closed-loop servo including temperature sensor, actuator, and feedback machanism, is incorporated. This is powered by the hot-air line pressure in which it is installed. The sensor is a bimetallic pencil controlling an air bleed, and the actuator a pressurized stainless steel bellows. Servo feedback is provided by varying an orifice by means of a taper needle.

Plessey's (66–68) **crew suit temperature controller** provides a variable supply of power to an air heater, under either manual or automatic control. The regulator temperature range on automatic is from 50° to 80°F and any particular setting may be maintained at ambients down to − 5°F. They also exhibit the type 4 **windscreen temperature controller,** consisting basically of a resistance measuring network.

Thermocouples and **temperature sensing** elements for installation on aircraft are shown by Technograph Electronic Products (151). J. Stone and Co. (Deptford) Ltd. (9) exhibit a **mercury-in-glass thermostat,** which they market in association with the (American) Vapor Heating Corporation.

Normalair (81) display the **electro-pneumatic pressure control** for the Vickers V.C.10. Long pneumatic-pipe runs have been eliminated by using electrically-operated pneumatic discharge-valves. Electrical actuation of the system is achieved by means of three sensing-elements, each consisting of a capsule operating a transducer: signals from these are amplified and combined to form a control signal for the discharge valve.

Actuation

A wide variety of equipment concerned with the many forms of actuation is on show, the majority being hydraulic. Boulton Paul (A) show **powered flying-control** units and **spoiler jacks** for the V.C.10, and **rotary control valves.** A wide range of **actuators** (rotary and linear) is shown by Western Manufacturing (217). An **aircraft brake control** system is demonstrated by Electro-Hydraulics (88). In this, the port and starboard brakes are supplied through separate relay valves which are in turn controlled by master cylinders operated by the pedals on a rudder bar. The pilot is made aware of the point at which braking commences by artificial feel.

Bristol Siddeley (239) are showing **re-circulating ball screws** which convert rotary to linear motion, and vice versa, with high efficiency and negligible backlash. Ball splines permit free telescopic movement irrespective of the torque being transmitted. Both mechanisms can operate dry at temperatures too high for normal lubrication.

H. M. Hobson (167) are exhibiting many forms of equipment, including **ball screw jacks** for the DH121, a tri-axis **feel-simulator** for the V.C.10, a **flap-control unit** for the wing-flaps of the A.W.A. Argosy, and **tandem-piston jacks,** a pair of which operate the all-moving tailplane of the Sea Vixen. They also show an **electro-hydraulic actuator** having a thrust of 1100 lb.

Fairey Engineerings' Hydraulic Division (231) are demonstrating what they claim to be one of the most advanced and compact **hydraulic-power control** units yet designed for an aeroplane. It can accept the usual manual input commands from the pilot and is fully duplicated hydraulically; it also meets the demands of an automatic stabilizing computing system. This means that slight tendencies to yawing or pitching are sensed by rate gyros and are automatically signalled (through an electro-hydraulic servo valve) to the hydraulic actuators. These then 'smooth out the bumps' in the aircraft's flight path without interfering in any way with the pilots commands.

Several hydraulic and pneumatic **servo-actuators** are shown by Turner Manufacturing (133).

Integral (166) show a range of **hydraulic power-units, pumps, motors,** and **constant-flow valves.**

The central exhibit on the Vickers (Detroit) hydraulic section of the Sperry stand (90), is the new range of fixed-angle **variable delivery pumps** in a working rig. A Spacemaster servo-valve controls a miniature hydraulic motor applied as a 'meter motor' (flowmeter). The pumps are available from 2·7 gal/min at 15,700 rev/min to 82 gal/min at 3880 rev/min; however, pumps can be run at up to 40% higher speeds, with a corresponding increase in the delivery. Sperry's Vickers section also features the hydraulic pumps and motors for the V.C. 10 and DH 121 aircraft.

Vactric (182–183) demonstrate an **actuator** working in an oven temperature of 200°C minimum, and controlled by a simple positioning servo. The motor tachogenerator operating the actuator is designed for a Bristol Siddeley high temperature jet engine.

Servos and ancillaries

Both Armstrong Whitworth Equipment (L) and Fairey Engineering (231) are showing electro-hydraulic **servo-valves.** The A.W.E. valve was described in our June (1960) issue, p. 123, and the Fairey device is shown in the working demonstration mentioned above under the heading 'Actuation'.

Ferranti's (176-177) **servo-control instruments** include a **hydraulic jet valve,** two types of **accelerometers** with ranges of ± 10 g and ± 25 g, and a new **angular-displacement-measuring transducer.** In the latter, a central primary coil is energized by a 20-V, 2400-c/s supply, to set up a flux linkage between itself and two outer secondary coils. The shaft whose displacement is to be measured, is connected to a copper shorted-turn which is moveable in an air gap in the central limb. With the shorted turn in the central position, the flux linkage between the primary and secondary coils is symmetrical and there is no output from the secondary coils. Displacement of the shorted turn from the central position disturbs the symmetry of the flux linkage and gives rise to a voltage output from the secondary coils proportional to the displacement.

Exhibits by the Servo Components Division of Elliotts (229-230) include **torque motors** for hydraulic and pneumatic servo-valve operation; **standard synchros,** including control transmitters and transformers designed for remote or local servo-system control, and torque transmitters and receivers for low-level transmission or indication of angular movement; **stub synchros,** which although considerably shorter than equivalent standard synchros have the same performance; **a.c. pick-offs,** for angular displacement or velocity; **miniature permanent-magnet servo-motors** (1-in. diameter or less); and **a.c. servo-motors,** to standard specifications.

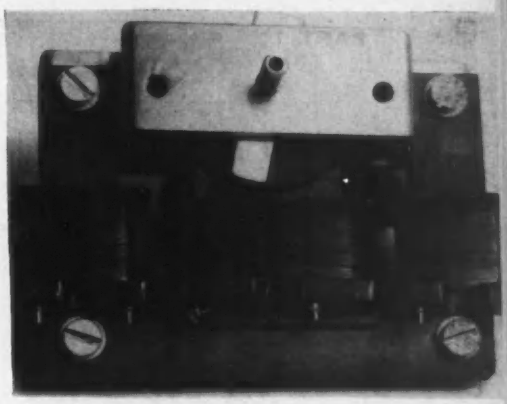
R. B. Pullin & Co. (253) are showing a range of size-18 **synchros** and size-15 and size-18 **servo-motors,** and precision **motor generators** for both 400-c/s and 50-c/s operation. They also have components for operation at high ambient temperatures (these have been developed in conjunction with Kearfott). Their new **transistor servo-amplifiers** include the TA.2 for 50- to 60-c/s systems, and the TA.3 which has been designed for operation over an ambient temperature range of −40°C to +85°C. A working **servo-system** using standard components, including a special gear-box assembly, demonstrates the various types of feedback loop which they can provide. Pullin are also showing a **remote position indicator** comprising a synchro input-element and servo balance indicator. The indicator provides an accuracy of ± 0·25° when operating from a standard size-11 synchro.

Smiths' (1-4) range of **synchros** is based primarily on frame-size 11, and a new range is now in production, covering many types of torque, control, differential and resolver elements. A similar comprehensive range of size-08 synchros is in a late stage of development and will be available for application where space is at a premium. **Slab synchros** are available in size 23, and size-15 slab synchros are under development. A wide range of **servo-motors** is in production in frame sizes 05, 07, 10, 11, 15 and 18, and a size-23 motor is under development. Size-11 **tacho-generators** are available with size-11 or larger motors. Two new **hysteresis motors** shown are size-07 and 11, producing 1 W and 8 W of mechanical output respectively. Smiths believe these to be the highest powers for these sizes so far produced.

Vactric (182-183) are showing a range of international frame-size equipment including **a.c. motors** and **tachogenerators, d.c. motors** (permanent magnet and split field) and **tachogenerators; in-line gearheads** with ratios up to 1000:1 are also shown. An interesting feature is a display of **'bread-board' servo-components** and **speed reducers.**

Among the Sperry (90) **synchros** and small electro-mechanical components on show are specialized devices originally developed by their Bracknell Division for specific missile applications: in particular, there is a precision **voltage-reference unit** with a stability factor of ±1 part in 10^5.

Newton Brothers (16) show two **servo-motors** which incorporate d.c. tachogenerators, and have outputs of up to 20 W and 90 W respectively; de Havilland Propellers (141) show **torque-motors,** and Plessey Group member Ketay (66-68) various developments in components and systems including a new **resolver** for navigational systems use.



A sensitive measurement of angular displacement is provided by this Ferranti transducer

Two **testing instruments** by E.M.O. Instrumentation (128) measure respectively the start- and running-torques in precision bearings, and the overall friction and electrical torque of synchros.

Guided Weapons

On show for the first time this year is the Avro **Blue Steel** air-to-ground stand-off bomb for the R.A.F.'s V-bombers.

A 60-ft model of the stern of a County Class warship carries a twin-barrelled launcher containing a boosted Armstrong Whitworth sea-to-air **Seaslug.** Guidance and control are by G.E.C. and Sperry.

Bristol-Ferranti's semi-active homing, surface-to-air, **Bloodhound,** now in R.A.F. service, is displayed with its launcher, part of a launch control post, and target-illuminating radar.

The Royal Artillery are displaying the English Electric semi-active homing, ground-to-air **Thunderbird** and four launchers, with two control posts, tactical control and illuminating radars.

The speed with which four Short **Seacats** can be fired is demonstrated by a R.N. team. These anti-aircraft missiles have now been ordered by the Royal Navy and Sweden, Australia and New Zealand are to adopt them, and N.A.T.O. countries are interested.

The de Havilland **Firestreak** air-to-air missile is fitted to the Javelin, Lightning and Sea Vixen. Firestreak can be fired at sub-sonic or supersonic speeds, and uses infra-red detection to guide it on to its target.

Space research is represented by the R.A.E.—Saunders-Roe **Black Knight.** On show is the second stage of a two-stage unit, built to investigate re-entry problems. Two-stage Black Knights have reached a height of more than 300 miles.

PART 1

Without inherent stability, jet-lifted aircraft present special problems. These remarkable new machines cannot be controlled by conventional aerodynamic methods. The foreseeable problems are closely studied in this review

Controlling v.t.o.l. aircraft at transition speeds

by **JAMES J. FOODY, M.SC., A.F.R.AE.S.**
Short Brothers & Harland Ltd.

OVER THE PAST FIFTY YEARS PROBLEMS IN STABILITY and control have exercised the minds of aircraft designers, and their ability to solve them has very often been the limiting factor in increasing the speed range or the altitude. With the opening up of the possibility of very short take-off and landing (s.t.o.l.) runs, and indeed *vertical* take-off (v.t.o.l.), a new field has been opened. Here there are conditions in which inherent stability is not achievable, and the aircraft designs will, by their very nature, be at best neutrally stable. Control also, below some forward speed, becomes impossible by conventional aerodynamic methods, and we are forced to consider new methods of providing control power and new methods of providing adequate stability; with, of course, their repercussions on reliability and safety. Control power is necessary for trimming and manoeuvring, and it is generally possible to assess how much should be provided. Stability on the other hand depends very much on pilot reaction, and indeed on pilot training, and it is not always possible without direct flying experience to predict how much stability is required in a new flight regime. We will discuss these problems in this article, show possible solutions, and indicate tentative conclusions which must wait until practical flying experience is obtained.

Much of this work is as yet largely theoretical and is backed up by only meagre flying experience. Certain problems will, however, undoubtedly arise, and whether analysis without flight experience has indicated an adequate solution remains to be seen. Most of the problems considered will apply to all types of v.t.o.l. and s.t.o.l. aircraft but the general discussion is aimed at the flat-rising type of vehicle such as the Short S.C.1, where the vertical lift is produced directly by lift engines. Other forms of flat-rising v.t.o. or s.t.o.l. aircraft, depending for their lift on ducted fans or boundary layer control, will involve much the same stability and control problems, although the airflow introduced may alter the picture significantly.

STABILITY

The designer of the conventional aircraft, by years of hard-won experience, has established the principles which enable him to achieve aerodynamic stability, at least over a large proportion of the flight range. At the approach speed, on aircraft with high-speed configuration, this stability becomes marginal and very frequently determines the minimum approach-speed, hence it is not unreasonable to expect that when the speed is further reduced by the provision of jet lift, attainment of adequate stability will become an important problem. Below we set out to explore the changes of stability which occur when an aircraft is partially or fully supported by jet lift at various forward speeds, thus considering both changes in jet lift and changes in incidence. It should be noted that this stability study is based on linearization of the dynamic equations of motion, and neglects both aerodynamic, inertial, and gyroscopic cross-coupling, although the effect of the latter is discussed.

An aircraft is normally supported by what we shall, perhaps rather loosely, call 'aerodynamic' lift, and in

order to keep straight and level the machine must fly at a certain angle of incidence. If, however, it is possible to apply a component of lifting thrust this can be looked upon as another variable and the aerodynamic lift coefficient C_L can be expressed in the form

$$C_L = \frac{W(1-\lambda)}{\frac{1}{2}\rho S V^2}$$

where λ is the proportion of the all-up weight borne on lifting jets. The relationship between λ, forward velocity V and C_L is shown in Fig. 1. It can be seen that the maximum lift coefficient available from a given wing no longer limits the minimum speed of flight, and that in the transition speed-range the pilot is free to choose an incidence at any speed and make up the remainder of the necessary lift on lifting jets. He is limited to some extent by stability considerations, and it will be shown that in both the lateral and longitudinal mode, stability is largely a function of speed and is only to a lesser degree influenced by the combination of incidence and jet lift.

Lateral stability

One of the limiting factors on conventional aircraft at speeds approaching the stall is the damping and frequency of the 'Dutch roll' oscillation.* This is very much a function of forward speed, and the results of

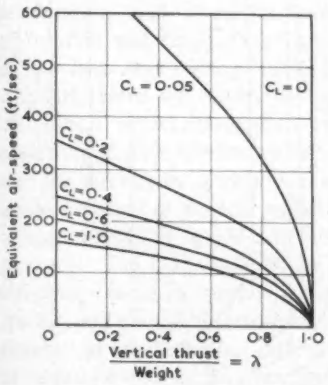


Fig. 1 Relation between vertical thrust parameter and air-speed

a simple linearized analysis are presented in Fig. 2 and Fig. 3. Fig. 2 shows that, at any given speed, as jet lift is increased and hence aerodynamic lift decreased, the period of the Dutch roll becomes longer; and also that as speed is reduced at constant C_L, the period tends to lengthen. Fig. 3 shows that there is a catastrophic reduction in damping as speed is reduced, and this is not significantly affected by the interchange of jet with aerodynamic lift. This general trend is likely to be present on any representative configuration, and unless particular design attention is paid to lateral characteristics, a Dutch roll instability will occur for even small reductions from conventional stalling speed. It may still be possible to use the fact that increasing jet lift will lengthen the period of the oscillation, thus making it more amenable to manual control; hence at any

* A wallowing motion at low speed.

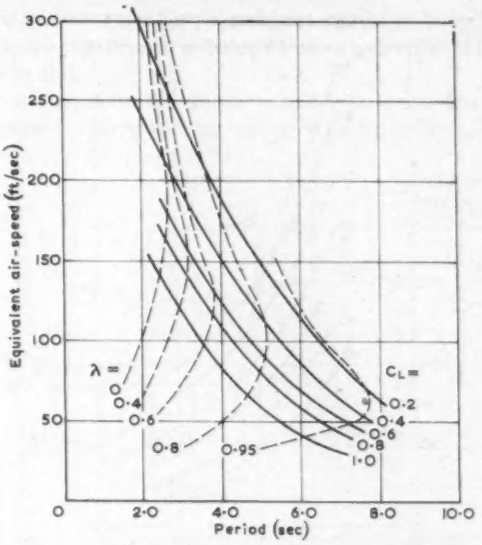
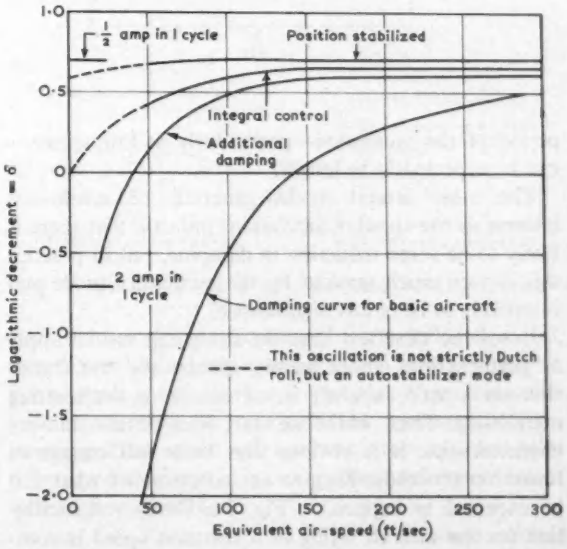


Fig. 2 Variation in Dutch roll period with air-speed

speed some improvement in handling characteristics can be expected from an increase in jet and a reduction in aerodynamic lift. This topic is discussed in more detail later in the article.

To broaden the general picture, the effect of one basic aircraft parameter, wing loading, on the period and damping of the Dutch roll has been examined for various combinations of jet and aerodynamic lift, and the result is shown in Fig. 4. It can be seen that an increase in wing loading will increase the period of the Dutch roll only slightly at low values of λ, but more significantly as λ increases. The effect of wing loading on oscillatory damping has also been examined and shown to be of second-order importance. Hence the results quoted here will apply in general to the more highly loaded v.t.o. aircraft of the future, although the

Fig. 3 Variation in Dutch roll damping with air-speed



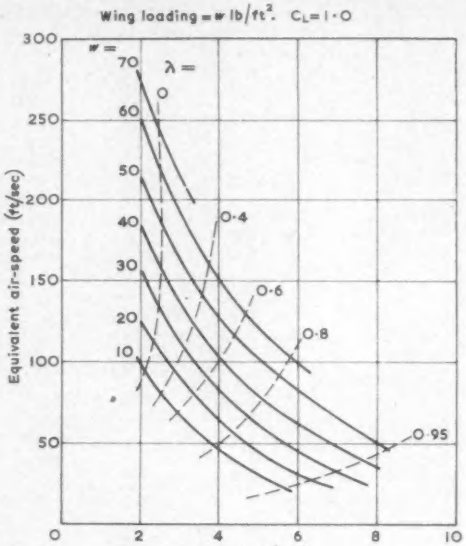
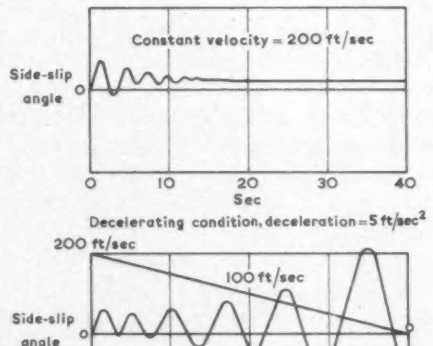


Fig. 4 (Above) Dutch roll period for different wing-loadings at constant lift coefficient

Fig. 5 (Below) Dutch roll oscillation with and without deceleration



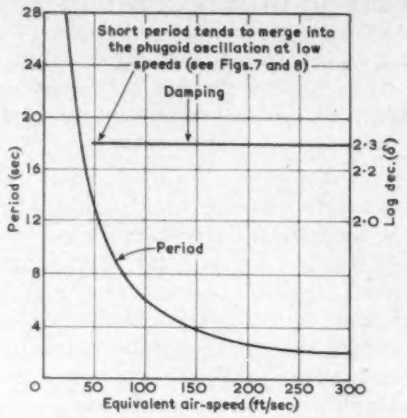
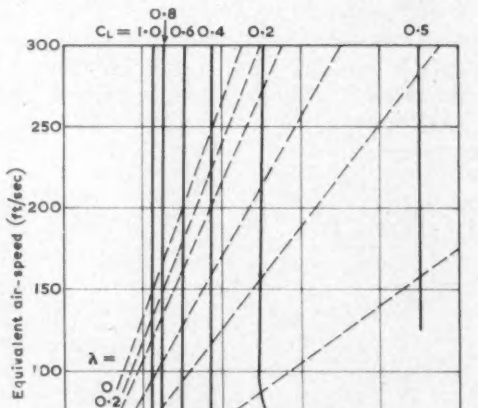


Fig. 6 (Above) Longitudinal short-period oscillation. Variation in period and damping with air-speed

Fig. 7 (Below) Phugoid period for various combinations of jet lift and 'aerodynamic' lift



period of the oscillation—particularly at low speeds—can be expected to be longer.

The other lateral mode, generally of much less interest, is the spiral. Calculations indicate that there is likely to be some reduction in damping, but in practice this is very much masked by the oscillatory mode and is unlikely to be of any significance.

It will be observed that the foregoing results apply to perturbations about steady speeds, and the transition on a v.t.o. aircraft is, of course, a decelerating manoeuvre. Thus, whilst we start with certain stability characteristics, it is obvious that these will change as transition proceeds. To give an indication of what can be expected to happen, in Fig. 5 a Dutch roll oscillation for the aircraft flying at a constant speed is compared with what would happen were the aircraft also decelerating at a representative rate. These results have been obtained from an analysis in which all the relevant non-linearities were included. The general tendency is for oscillatory period to increase and damping to deteriorate. This shows adequate correlation with the quasi-steady characteristics shown in Figs. 2 and 3, and the inference is that any conclusion drawn from the quasi-steady condition is unlikely to be significantly altered by the inclusion of the acceleration terms.

Longitudinal stability

Conventionally the longitudinal motion of a standard aircraft breaks down into a poorly damped, long-period oscillation, known as the 'phugoid', and a

highly damped, short-period oscillation which can, under some circumstances (particularly those of high speed), become divergent. An investigation into the stability of the short-period oscillation with decreasing speed has shown the normal tendency for the period to lengthen, but has not uncovered any significant tendency for the damping to deteriorate beyond what might be considered acceptable. These effects are shown in Fig. 6. The effect of speed and λ on the period and damping of the phugoid is shown on Figs. 7 and 8, and again we see that the general effect of increasing jet lift at the expense of aerodynamic lift at any speed is to increase the period of oscillation. Damping again is shown to be largely a function of speed, but as the period is so long this oscillation does not take on nearly the same importance as the Dutch roll oscillation.

Hovering stability

As speed is reduced, and the aerodynamic forces become of less and finally no importance, the general stability equations on which the above analysis has been based break down, leaving only inertia effects. In this case both lateral and longitudinal equations are similarly expressed as an inertia-force relationship, but in the absence of any restoring forces cannot be said to possess any stability properties such as period and damping. Hence a force will merely cause an angular acceleration, and when the force is removed a rate of rotation will result. One significant effect, however, in the case of hovering stability, is gyroscopic cross-coupling. Here we confine ourselves to consideration of aircraft in which engines are mounted to rotate about the Z axis. Gyroscopic effects will tend to maintain the aircraft in its steady-state attitude at any time, hence assisting in general stabilization but introducing cross-couplings in response to either control or external moments. The magnitude of the stabilization or cross-coupling effect is purely a function of the engine inertia, and should therefore be a minimum for a large number of small engines rather than one large engine. It could, of course, be overcome by having right- and left-handed engines, and this may very well prove to be necessary in specific cases.

When a rolling moment is applied to the unstabilized aircraft in the presence of gyroscopic effects, the rate of roll resulting will cause a force in the pitching plane, producing a pitching disturbance. Fig. 9a shows the magnitude of this effect in a particular case. Here the aileron is applied to cause a roll, and the roll is stopped by reversing the stick displacement. In the meantime a pitching acceleration has caused a pitching attitude-change, and it can be seen that for the particular engine and aircraft considered the pitching change is of the same order as the bank-angle produced, and the expected steady state is not achieved. In order to correct for this cross-coupling effect it is necessary to apply a pitching moment to oppose the pitching moment due to roll and it is shown in Fig. 9b that something of the order of a quarter of full stick in pitch is required to counteract the cross-coupling effect in a manoeuvre initiated by the application of full stick in roll.

In the light of the above evidence it seems fair to conclude that, even for small reductions in speed

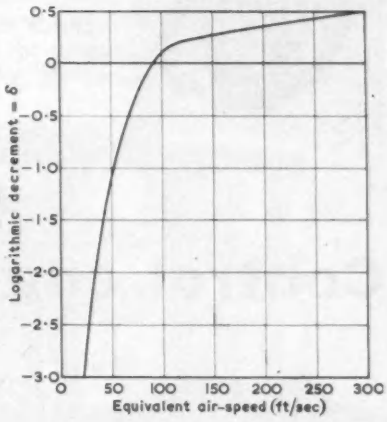


Fig. 8 Damping of phugoid oscillation

gained by the use of jet-lift techniques, there is a rapid deterioration in stability characteristics. The general picture is one of increasing period and decreasing damping. Hence, for s.t.o.l. aircraft intending to use lift-augmentation, serious consideration should be given to the minimum speed which can be reached without some form of stability augmentation. For v.t.o.l. aircraft the aerodynamic modes of flight will, in general, persist with decreasing speed down to very low speeds, but at these speeds there is a condition of neutral stability complicated by a significant gyroscopic cross-coupling effect which will render control by a test pilot difficult, and control in an operational environment well nigh impossible.

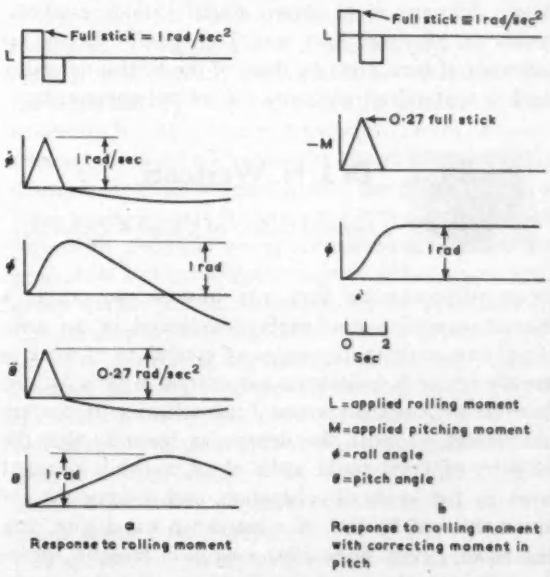


Fig. 9 Gyroscopic effects on unstabilized hovering aircraft

To be continued

Three British authorities, Dr J. H. Westcott, Dr H. H. Rosenbrock and Professor J. C. West, describe what they saw in the Soviet Union after the formal proceedings at the Ifac Congress

Control engineering in the U.S.S.R.

THE FIRST INTERNATIONAL CONGRESS OF IFAC (THE INTERnational Federation of Automatic Control) was held in Moscow from 27 June to 7 July last. The first week of the congress was spent in formal conference, and an interpretive review of the papers and discussions appeared in *Control* last month. During the second week, delegates were shown round various establishments in Moscow, Kiev and Leningrad. Below are accounts of their visits by three of the British delegates, each a well-known authority on control engineering.

Dr J. H. Westcott

Imperial College of Science & Technology

IT IS DIFFICULT TO GIVE THE READER (NO DOUBT A bloated capitalist comfortably ensconced in an armchair!) an accurate impression of conditions of work in the top research-institute on automation in Moscow, the Institute of Automation and Telemechanics. If you are old enough to recall the depressing barracks that the Ministry of Food could make of an erstwhile pleasant hotel by five years of occupation, and imagine the exterior replaced by that of a run-down warehouse, you can make a start. Even after a week in Moscow, practising the art of not judging things by what they seem, it still came as a surprise to me to find when I visited the Institute that I was really at the right place.

The reception of delegates on visits followed a set pattern: the director (Academician Trapeznikov at the Moscow Institute) made a statement concerning activities, expressed a hope that we would discuss our work with his people working on similar problems, and invited us to make any criticisms that seemed justified. We found this stress on criticism rather difficult. It really called for more subtle diplomacy than most of us were accustomed to exercising. The net result, of course, was that we said very little, and were no doubt thought to be rather selfishly taking everything in without contributing anything in exchange. After the introductory talk questions were asked for, and the replies were often the most interesting part of the visit. Skilfully placed questions at this stage could produce devastatingly revealing answers. On the other hand it appears to be almost an axiom in Russia that there is no point in giving information that is not specifically requested.

MUSCOVITE ICEBERG

At the Moscow Institute we did reasonably well. Before we left the Director's office we had elicited the following information. The I.A.T. employs some 400 scientists and has ten main groups, each headed by a well-known name working in a defined field. Salary for a scientist having a doctorate is (on tourist's rate of exchange*), about £170 a month, and £110 a month for the less qualified: but income tax and rent are very small. The Institute has no direct connexion with the University of Moscow, where some rather modest research is done (described as 'not serious'), but it employs about seventy post-graduate students of the University, and Institute scientists do some lecturing at the University. The Institute has a group of 25 people who translate documents in any language and reckon to see all available literature in subjects of interest. On the question of financial support, they said that under a planning system this was no problem, but they agreed that buildings and accommodation were generally very difficult. New buildings would be provided by the Government under the planning scheme when justified. They

* *It is hard to translate roubles into comparable Sterling figures. Delegates at the Ifac Congress received 28 roubles for their pound. For some other transactions the rate is pegged at eleven roubles. It is perhaps impossible to say what the 'real' relative values may be.*—EDITOR.

gave us to understand that this would be very soon now. The Institute was proud of being a pure research establishment and had no particular responsibility for seeing that work was applied, but they confessed to making a few special equipments, ' for which purpose we have a few mechanics '. In fact, the chance of getting work done outside is so small that the Institute make practically everything in their own backyard, and this requires a high proportion of mechanics by our standards. This pattern was repeated at each institute I visited in the Soviet Union.

The Moscow Institute has a very energetic group working under Professor Aiserman on pneumatic and hydraulic devices. In the view of this group pneumatic devices are more reliable, simpler and more appropriate for the long time-constants involved in process control. An extremum regulator (see Fig. 1), composed of standard pneumatic units of their own construction, but clearly owing much to the well-known stack-type of instrument, was demonstrated controlling mixing of HCl and NaOH; the extremum here was maximum temperature. Sinusoidal perturbation was used for probing.

A special feature was the development of low-pressure (100 mm Hg) computing devices whose success depended on a high-gain pneumatic amplifier based on the flapper-nozzle principle. Function generation was by exploiting the distribution of pressure across a jet. Another break with tradition was the development of a miniature pneumatic relay (about 1 in. cube) which was used as the basic component for building up logical schemes, involving say fifty relays, and a pneumatic memory device (equivalent of electronic ' clamp ' unit). This group seemed to be mechanically ingenious and well-informed in their subject. It was not easy to find out why such heavy emphasis was being placed on this, particularly in an institute which spurned connexion with practical applications.

The other enterprising group was the one working under Professor Feldbaum on automatic probing and extremum regulators in the laboratory of self-adjusting systems. We were shown a demonstration of a single-variable stepping-type hill-climber which faithfully reached its extremum after eight steps, working at a rate of one step a second. This was not very exciting, being a noise-free case without dynamic lags in the process. A hand was waved in the direction of larger boxes, which we were told were prototypes of production models for five-, ten- and twelve-channel optimizers.

At this stage Dr Leonov, who had taken part in the discussion of my paper at the Congress, and who works at the Institute, took me aside to discuss common problems. His office was a thin aperture between two rooms, partitioned off. At one end were an easel and blackboard (as wobbly as any western version), at the other his desk and a most curious piece of furniture looking like the leather upholstered seat from a railway-station waiting-room. On this we sat until the language difficulty drove us to diagrams on the blackboard. His English was no better than my Russian! Only when we were joined by the lab. boy (whose English was, needless to say, excellent) did communication really commence. Dr Leonov is a member of a newly formed group under Professor Pugachev (author of a recent massive tome on random function theory). The work they are doing is highly theoretical. I would suppose that Pugachev is possibly part of the submerged nine-tenths of this iceberg-like Institute, the excellent applied-mathematical

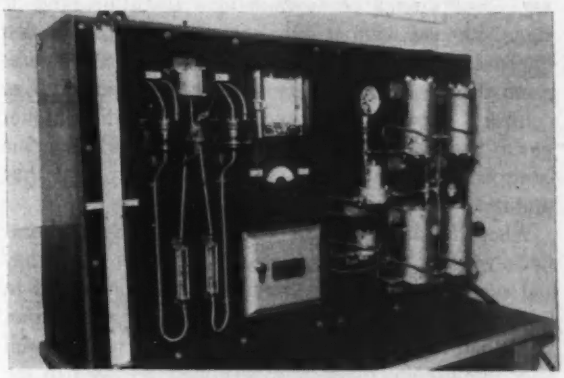


Fig. 1 Pneumatic regulator for controlling mixture of HCl and NaOH

theorist whose influence on progress is so difficult to assess and whose efforts as yet are barely visible in the physical apparatus on show.

CITY OF LIGHT

The next visit was to an institution in Leningrad. Leningrad is recognizably a European city, the city of light; artistic light at any rate, if not technical light. However, half of what we saw at the Institute of Electromechanics was concerned with the control of optical telescopes, so one might concede that point too. Director Kostenko told us in English that the Institute controls three establishments in Leningrad. It is concerned primarily with electrical power transmission systems, both generation and transmission aspects. It has a very active group working on the modelling of large generators and transmission systems. In addition it has groups working on relay protection, regulation, traction and telescope controls. Its work is centred in the area covered by the S.E.G.R.E., but it had contributed two papers to the conference. We were shown the laboratory of power system studies under I. E. Gelebov where electrodynamic modelling of generators is carried out using micro-machine techniques.

The other laboratory seen was the laboratory of automatic control and precision mechanisms, where telescope control was investigated. This again was a self-contained group for complete design of automatic telescope controls. The main laboratory (40 ft × 80 ft) was itself a museum piece of baroque art, preserved in the face of its present occupation by ' scientists '. This room contained everybody involved, that is to say typists, draughtswomen, technicians and scientists, together with miscellaneous servo-gear; eight women and six men in all; with six more people in the test room. A photo-electric sys-

tem had been worked out for continuous control of the telescope to an accuracy of 1/16 in. over several hours. The control scheme was a straightforward one, following photo-transistor and photo-multiplier with magnetic amplifier, valve amplifier and metadyne motor-generator set, and so to servo-motor with tacho-feedback from the output shaft (dc. for large systems; a.c. for small) and a notch network in the feedback path. Accuracy claimed at the photographic plate was 2–5μ for normal following. Results on a photograph of a seventh-magnitude star, with and without auto-control, convinced us that improvement was being achieved, although the figures given did not help us very much. The band-width of control is a few cycles per second since the whole mount has to be moved. We asked why they did not have a fine control moving the photographic plate only, and they said they had heard of the method.

When the design is complete batches are made outside—we saw a prototype so manufactured, and they had our sympathies. We may have been influenced in this feeling by the fact that our stay, like all Russian visits, had run behind schedule, and it was by now well after our normal lunch-hour. We were returned to the care of the Intourist organization, which in Leningrad was operated with a light touch that was almost a pleasure after Moscow.

ALL GOOD COMRADES TOGETHER

And so to Kiev, which (make no mistake) is in the Ukraine, and that makes a difference. It was very much overrun during the war, and the amount of rebuilding is quite amazing and goes on apace. The people have been rebuilt too, it seems. At any rate they have that friendliness of people who have just moved in to a new housing estate. The Institute of Automation surprised us by being housed in a fairly up-to-date new building, and by opening the proceedings with the issue of white overalls. We were then ushered into Director Melnik's office and the opening speech.

We were told that problems of 'complex' automation were being tackled (i.e. automatic control of complete plant). There followed the period of answering questions—which we were ready for this time—and which was in this case particularly rewarding. We started by asking, as everywhere, 'Do you collaborate with the Institute of Automation and Telemechanics in Moscow?' Answer: 'We know of their work and they of ours. We interchange specialists occasionally. We have a system of co-ordination, conferences and so on, held in different republics. We publish details of our work in our journal, *Automation and Machine Construction*. There are agreed aims to our research work'. Asked in what areas complex automation had proceeded furthest, they said in the power industry and parts of the chemical industry; also metallurgical and machine-tool industries as elsewhere. We asked how they got their problems and were told that they were received in the form of requests from the users. Asked whether they could undertake work that had not been requested, they said there would be no point: 'This is a research institute. We are not a planning institute. During our work we do sometimes incidentally discover instruments which could not have been planned. Gosplan is the planning institute and it has many branches with specialists attached to them. When an enterprise wants research done this is sometimes arranged directly with the Institute, sometimes through the Council of the Academy, and also through Gosplan. If feasible and agreeable it is included in the Institution plan sent to the State Commission for confirmation'. Asked what they did when a fundamental problem arose, whether they tackled it themselves or whether they sought assistance, they answered—to our surprise—that they had no experience of this sort of thing. We enquired who decided which work should continue when duplication occurred, and they said that preference was usually given to those that are most effective; the choice being exercised by the user. Once the user has agreed to take automation in some form, the Institute lends experts who establish their own laboratory on the premises and work there continuously until the job is complete.

Then followed the tour of the establishment. As a development concern, it was the only place we saw that looked more or less as one would expect. The amount of equipment was a bit thin, but tolerable; there was still the tendency to push all and sundry into one laboratory. Draughtsmen were mixed with wiremen and typists—all good comrades together, no doubt. This Institute distinguished itself in that great enthusiasm and a more comradely spirit seemed to exist among the staff; the Director, for example, moved freely among his people, talking to them as equals. It did seem to us elsewhere that pecking orders were fairly rigidly observed in general. We were first taken to demonstration rooms, where examples of the type of apparatus being developed in the Institute were on show. Much of this was in fairly elementary forms of automation, such as relay sequencing controllers, programmed devices for replacing manual operation, and stepping electronic controllers for control of temperature, pressure, flow, requiring an electrical transducer for input and an electrical actuator for output. Various forms of sensing devices for special purposes were shown; a radio-active β-source (10 mc strontium-90) for measuring the thickness of rubber in tyre production at the new Dniepropetrovsk plant; a 2%-accurate radio-active device for flame-temperature measurement; concentration measurement in a two-component solution by measurement of velocity of sound at 500 kc/s, with 1% accuracy; a transistorized analogue device, using ferro-magnetic sensors, for optimum control of efficiency of furnaces.

Finally we were once more shepherded into the Director's office for a discussion and a hearing of our criticisms. The time, in the usual Russian fashion, was under loose control. By now it was ten past two, and most of us had our internal data-loggers printing out

off-normal in dark red symbols. When we rather shortly dried up in the discussion, the Director announced that his experts would now like to ask *us* some questions, and they set about fulfilling their norms with gusto. In due course we moved to the final ceremony; the taking of the photograph on the Institute steps and the returning of the white overalls. In fact, we had found this visit the most interesting of all, although our enthusiasm on parting was perhaps tempered by our weary feet. And so back to Moscow, the eye of the needle, the only eye through which you may depart to the outside world, if it exists.

Dr H. H. Rosenbrock

Constructors John Brown Ltd

Below is a straightforward account of my visits, made during the Ifac Congress, to applied research establishments, machine-tool factories, and a power station in the U.S.S.R.

APPLIED RESEARCH

Disappointment in Moscow

The Moscow Institute of Automation and Telemechanics, U.S.S.R. Academy of Sciences, which is well known for its theoretical work, is housed in a somewhat ramshackle building. We were shown first various examples of equipment built to optimize a control system automatically. The principles embodied were those of Feldbaum, and they were described at the conference in a paper by Stakovskiy *et al.* The search techniques used either the steepest-descent or the 'gradient' method. The latter differs from steepest-descent technique in that the gradient of the response surface is evaluated at every step, and not when progress along the last direction has ceased. The region of optimization could be limited, but the procedure for this purpose did not appear to be very efficient. One piece of equipment (Fig. 2) showed a function of two variables, specified by twelve coefficients, being optimized by adjustment of the coefficients.

In another laboratory we saw pneumatic logic elements which had been described at the conference by Berends *et al.* These were small pneumatic relays (about $1\frac{1}{2}$ in. square by $\frac{3}{4}$ in. thick). We were told that they could be built into a computer to give greater reliability than can be obtained from electronic devices. This seems doubtful, but on a later visit in Kiev the relays were seen in a quite natural application. They were used for switching pneumatic connexions to the electric-to-air converter of an electronic process-control computer.

More work on pneumatic elements was shown in another laboratory. The effort being devoted in the U.S.S.R. to the theoretical and experimental investigation of pneumatic elements was surprising. It was taken by some to indicate that Russian solid-state electronic devices are not yet freely available (or perhaps not yet very reliable). However this may be, some of the pneumatic devices had considerable interest. In one a movable nozzle was traversed across a jet. By means of feedback the device could be used as an operational amplifier; or, by shaping the jet, it could be used as a function generator, though one would imagine it would be a difficult one to design or adjust.

Hydraulic mechanisms were also being studied. There was a hydraulic servo-mechanism on show which was actuated either by a pressure or by an electrical input signal. The device was about 9 in. long and 4 in. in diameter, and it actuated a crank. A hydraulic controller with proportional and integral action was remarkable: it seems odd that one should want to generate such an action hydraulically. The device was similar to a stack-type pneumatic controller, but owing to the incompressibility of the fluid a bellows and spring were needed to obtain integral action.

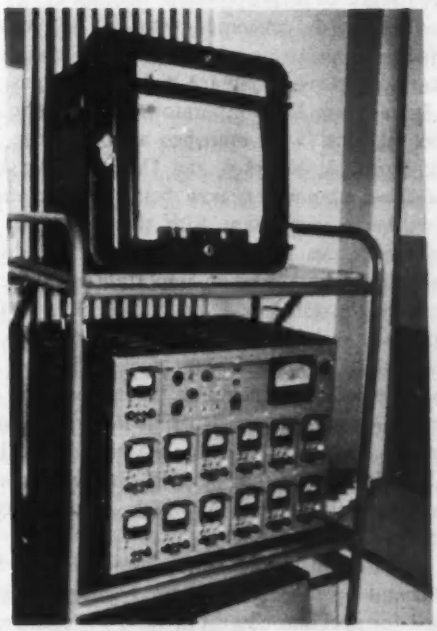


Fig. 2 This rig at the Institute of Automation and Telemechanics was described as a device for optimizing a twelve-variable system

A pneumatic stack-type controller was exhibited. It was combined with a number of pneumatic relays into a control device which carried out an automatic optimizing routine. The details of the routine were not explained. In another laboratory we saw a small analogue computer consisting of amplifiers set up on racks. The equipment seemed poorly made and out-of-date, and it was remarkable that the Institute had no large analogue computing facilities, nor did it have its own digital computer. We were told that it relied on a computing centre for both these services.

The general impression of the visit was disappointing. A few of the ideas incorporated in the equipment were interesting, but the equipment itself did not seem

to have any great value. One had a definite impression that the Institute is a centre of theoretical work, and is out of touch with practice. It seems to do experimental work without much enthusiasm. The laboratories and the equipment available make any advanced or practical investigation impossible.

Refreshment at Kiev

The Kiev Institute of Automation, Ukrainian Academy of Sciences, was set up in January 1958 (or possibly in 1957—both dates were given). It is in a new building, very different from the building of the Institute of Automation and Telemechanics in Moscow, and well suited to its purpose.

The Institute is concerned with the automation of manufacturing processes in the chemical, coal, mining, metallurgical, power, machine-building and gas industries. It has over forty laboratories and is the centre for the Ukraine, with branches at Zaporodze, Lisitchansk, Lugansk, Kharkov and Dniepropetrovsk. The last of these branches is now being set up, and presumably has a connexion with the dam and power station which are being reconstructed. The Institute also operates laboratories in important manufacturing plants. It has a staff (including branches) of 2000, and it is planned that this will increase to 6000 in 1965, by which time the buildings in Kiev will cover about 120 hectares. Similar institutes have been set up in Armenia, Georgia and the Russian Federation, though the one in Kiev was said to be the largest. In the U.S.S.R. it is planned that by 1965 fifty enterprises will be completely automated, of which about fifteen will be in the Ukraine.

We saw a control panel which had been built for an experimental open-hearth control. The equipment was arranged for program control of fuel, air, pressure, and heat exchange, and eight or more periods could be dealt with. Periods were terminated either on a basis of time or on completion of the process. The duration was from two to fifteen hours, though the equipment was suitable for up to 45 hours.

In another laboratory we were shown a number of controllers. These appeared to be largely of the on/off variety, and could be either single-point or multi-point. There was also a device which allowed more than one process to be controlled by a single on/off controller, provided that the processes were identical.

An instrument for measuring concentration in two-component systems used transmission of ultrasonic waves (500 kc/s). One version used valves, another transistors. An accuracy of 1% was claimed, but the effect of temperature had not yet been studied. An ultrasonic level-detector, working by transmission through the liquid in the container, was also seen.

The process-control computer already mentioned was being developed at Lisitchansk, and only circuit diagrams and a display cabinet were shown. Two versions of the equipment were being developed. One with sixty inputs was intended for chemical plants and would be installed this year. Inputs were coded at source (electrical contact disk) with eight or nine bits. Output was binary and was converted to a pneumatic signal. Apparently on/off output signals were not ordinarily used for control. Pneumatic outputs from the electric-to-air converter were switched and stored between cycles by means of pneumatic relays and memories developed at the Institute of Automation in Moscow. The larger machine worked with fourteen bits, fixed point, and had overflow alarm. It would make 750 additions a second or ninety multiplications, and could be used for optimizing. Both computers used solid-state devices throughout.

One laboratory was working on the automation of machine tools. In 1959, in collaboration with the factory concerned, it developed a program-controlled turret lathe for stepped work. Input was from punched cards, and electrical servo-mechanisms were used. Ten of the machines were being built. Another program-controlled machine was intended for the automatic cutting of ships' plates. The Institute was collaborating in this development with the computing centre and with the factory concerned with manufacture. The program was stored on magnetic tape produced by a computer. Seven channels were used, two for each co-ordinate and three for technological commands such as flame control. A small model of the automatic flame-cutting device was shown in the laboratory. We were told that the accuracy of the full-size machine would be $\frac{1}{2}$ mm. It was to be built this year, using stepping motors 280 mm in diameter by 350 mm long, with sixteen steps per revolution, capable of handling 200 pulses a second and stopping within one pulse.

A remote-control equipment had been developed for oil-field use, serving thirty points, each with seven bores, and handling 1500 channels. It used germanium transistors and magnetic elements, and received information on pressure, flow and temperature. A high-frequency telephone line was available and the main carrier was at 40 kc/s. Metering signals were in the range 1500-3000 cycles and alarms at 6 and 7 kc/s, in both cases amplitude-modulated on the carrier. Provision was made for alarm signals in two categories with automatic break-in and queueing.

This was a most refreshing visit. The Institute was concerned with the practical problems of industry, and not with unapplied theory on the one hand or elementary automation in out-of-date factories on the other. To say this is not to belittle the work elsewhere in Russia. The Institute was set up only $2\frac{1}{2}$ years ago, and before then, no doubt, there was insufficient trained manpower for such work. Moreover, until the work of such institutes begins to make its impression the general level of automation in industry cannot help but be backward. The work going on in Kiev was very competent and there was unlimited enthusiasm on the part of the staff. The scale on which the work is being carried out is impressive, and when its results are available, and have been incorporated in industry, we should

see a very different type of factory from the machine-tool factories described below.

MACHINE-TOOL FACTORIES

Unsafe in Moscow

The Krasny Proletariy machine-tool factory is housed in rather cramped premises in Moscow. We were told that the factory had been partly destroyed during the war and repaired afterwards. The rebuilding was to a very minimal standard; as an example, the unevenness of the floor must have constituted a hazard to workmen and contributed to the difficulty of cleaning. Cleanliness, in fact, did not seem to be considered a great virtue in this plant — dirt had accumulated under duck-boards, floors were greasy and machines

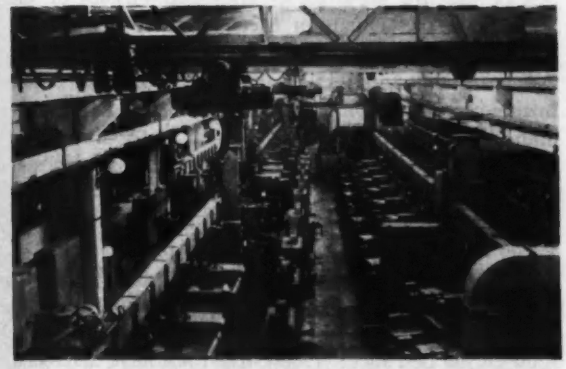


Fig. 3 There are already several shops for automatic production at the bearing factory in Moscow. One of these shops is shown in the illustration above. Under the seven-year plan about 80% of production is to be fully automatic at this plant by 1965. Feedback systems will be used in grinding and other precision work, and new manufacturing processes (mainly mechanical-working procedures at present in the laboratory stage) will be substituted for cutting processes. The output of the plant comprises over 1000 types and sizes of bearings, ranging from 28 mm to 1·6 m diameter

were dirty. Part of this may have been due to three-shift working, but efficiency must have suffered from the untidiness and from the poor layout of machines.

Automation in the factory was represented by an automatic transfer line for gears, and was disappointing. The line consisted of nine machines linked by a simple automatic transfer device. The machines had been bought out by the factory, but the transfer device had been designed and made there. Gear blanks were first turned on the top face in a vertical lathe. They were then up-ended in the transfer device and turned on the other face in a second lathe. The bore was broached to produce splines and the circumference was turned in a fourth machine. There were then three hobbing machines, every third blank going into each machine so that these operated in parallel. Finally the ends of the teeth were rounded in two consecutive machines. The whole line waited until all nine machines had finished their operation. The transfer device then moved, and after all the machines had been loaded the next cycle began. Gears were taken by hand from the end of the line for flame hardening.

This factory left a rather poor impression. There was little attention to safety (none of the machines had guards, unguarded belts were running next to narrow gangways with uneven floors, and so on). Layout of machines could have been improved and so could cleanliness. The automation was rather trivial.

As bad in Leningrad

At the Sverdlov machine-tool factory, Leningrad, we were taken first to the development laboratory, and details of the automatically controlled machines which they manufacture were explained. Control of the machines is based on a speed-control servo-mechanism using an amplidyne, with feedback of speed and its first and second derivatives. The speed range was said to be from 1 to 4000 rev/min in the laboratory, and a range of 2000:1 was obtained in practice. When it was used for position control the speed servo-mechanism was fed with position error together with its derivative. At the same time the feedback of second derivative of speed was eliminated. The servo-mechanism was said to be sufficiently stiff to give, with ordinary slides, an incremental movement of 1 μ with a 5-ton load and 20 μ with a 20-ton load. Because of this the factory claimed to be able to produce the largest copy-millers in the world.

Working conditions in the factory were not very different from those in the machine-tool factory seen in Moscow. It appeared that attention to cleanliness and layout of the machines would have increased efficiency, and it was difficult to see how machines of the accuracy claimed could be produced in such conditions.

EFFICIENCY AT A POWER STATION

Power station 20 of the Moscow power system was built in 1952, and supplies the south-eastern region of Moscow. It has a capacity of 150 MW and delivers 500 million kcal of heat per hour for district heating by hot water. In winter the station is run on Donbas coal, and in summer it uses natural gas which is piped from Surata in the Ukraine, 1000 km away.

The automatic control system of the station was explained to us, but it was difficult to be clear just how far the system was integrated. There certainly was not overall control of boilers and turbines based on power demand. On the other hand, three-element boiler control was used and a measurement of oxygen in the flue gas was used for control of the furnace conditions. The boilers had local control panels and one operator supervised three boilers.

We were told that the boilers had been produced in the Taganbrod plant. They appeared to be well designed, and everything was very clean and in good order. The appearance of the control panels, which were installed in 1955, was somewhat out-of-date. All valves were operated by electric motors through gearing. They were controlled by three-position electric controllers (forward, off, backward), using cold-cathode valves followed either by a relay or by a magnetic

amplifier. Magnetic amplifiers were replacing relays, presumably for greater reliability. One would not expect the speed of control with such a system to be as good as with pneumatic control.

None of the control equipment that was seen was particularly up-to-date. The most surprising feature was the use of geared motors for valve operation, combined with on/off controllers. The general impression of the station was one of competence and efficiency. Everything was neat and in good order and the Superintendent of the power station was obviously proud of it.

Professor J. C. West

Queen's University, Belfast

The Leningrad Institute of Electrical Engineering* was one of the many establishments visited by Ifac delegates. This was established 75 years ago, and it is primarily concerned with the teaching of students, although extensive research is carried out by staff and research students. We were informed that there are now six institutes for electrical engineering in the U.S.S.R., all based on the Leningrad model. They are all of the same size, but only three others were named: Moscow, Tashkent and one in Siberia.

Before the last war the main emphasis in the teaching at the Leningrad Institute centred round hydroelectric power and high voltage, with some classical radio theory as subsidiary. During the last ten years major changes have taken place, and now the Institute is divided into six faculties: Radio Engineering, Electronic Devices, Business Automation and Computing, Industrial Automatic Control and Applications, Electro-physics (Acoustics, Ultrasonics, Dielectrics and Magnetics), and a technical college for part-time day and evening students.

The full-time course, extending over five years ten months, leads to a Diploma of the Institute. The vacations consist of two months in the summer and two weeks in midwinter. The year is divided academically into two terms. There are some 6000 full-time day students (20% female) and another 1000 part-time students. Classes in the lecture-theatre number over 200, but the main teaching is tutorial, and is done in groups of 25. There is a total teaching staff of 500, and none of them has a student contact time of more than 500 hours a year. Some, at the discretion of heads of departments, have considerably less teaching time and increased research responsibility. At present the staff has thirty doctorates and 250 admitted candidates doing research for their doctoral degree (awarded by the University).

Entrance is obtained on the results of a competitive examination set by the Institute, the results being considered by a collective industrial board. There are five times more applicants than there are places available for them. Successful students automatically obtain a maintenance grant from the Government. The subjects of the entrance examination are Mathematics (pure and applied), Physics, Russian and one foreign language; English is the most popular, with German next. A few take Chinese. The age limits are 17 and 35, but the vast majority at acceptance are between 18 and 22 years old. There is an examination every six months, which the student must pass in order to proceed to the next stage. The total failure rate from start to finish is less than 10%. This good figure is thought to be due to the high standard at entry. It could also be due to the incentive financial bonuses awarded for good performance.

The first two years of the course are common to all electrical students, but from then on the student selects one of the five departments, although Physics of the Solid State and Quantum Mechanics are compulsory for all. Engineering Drawing is not neglected, the first two years containing 150 hours in the drawing office. In their specialization, more attention is paid to theory than applied technology, and with successive years more time is spent in the laboratory and less in formal lectures. The total hours per week also decrease from 34 in the second year to 24 in the last two years.

The last year is devoted to a minor piece of research work. The thesis of this work is presented for the award of the final classification of the Diploma. The classification determines starting salary in industry. Some of the best theses I saw would not have disgraced a Ph.D. candidate in the United Kingdom, but others were equivalent to project work reports of our own undergraduates. The projects are examined with a *viva voce* by a state examining board composed mainly of industrialists who offer positions in their particular concerns. Few fail at this stage. This board also makes suggestions to the institute for further project work.

Research work in the Institute itself is considered the peak of achievement by the new graduates. The gifted person is chosen by the Professor as a research assistant, with an attractive salary higher than that obtainable on entry into industry. The research leads to the Doctorate of Engineering Science, and normally takes three years full time. Further research work prepares a man for entry into the Academy of Sciences.

For those who go into industry, there is an opportunity to return for advanced courses, or research, after two years. They must sit for an institution examination consisting of two papers, one in the specialist subject of their own choice and the other in philosophy.

The number of industrial vacancies available is determined by a centralized state-planning authority in Moscow. The students with the highest awards have first choice from the list, but there is no compulsion at any level. There are more vacancies than diploma students.

In the course of their six years, some eighteen months are connected with industry in an integrated fashion. The student must also get proficiency certificates in swimming, skiing and politics.

* Director, Prof. N. P. Bogoroditski.

Work on learning machines has so far only scratched the surface of what is possible: but learning devices will certainly become a part of process-control systems in the future

Learning in control systems

by **A. M. ANDREW**
National Physical Laboratory

A HUMAN BEING CAN READILY LEARN TO PERFORM TASKS which are not amenable to automatic control, or which can be mechanized only with extreme difficulty. Examples of such tasks are driving a car and translating between two languages. Often a human operator performs with considerable efficiency without having a detailed knowledge of the physical system with which he is dealing. For example, many people who drive skilfully know very little about the arrangement of springs, linkages and shock-absorbers which form the suspension of their cars, although the details of these arrangements determine the handling qualities of the vehicle. An automatic device to control a car as efficiently as a person would need to take account of the properties of the suspension, and its design, would be based either on a detailed mathematical analysis of this mechanism or on empirical data obtained from tests on an actual vehicle.

It is obvious that the technique adopted by a person is not based on a detailed mathematical analysis of his car; it is, in fact, based on empirical data which he collects while actually driving. In a rather similar way, good language translation depends on knowledge of the languages which is invariably derived from experience of their use rather than from a study of the textbook rules.

Many interesting and useful things could be done by machines which were able to learn from experience as a person does. Learning devices will certainly be incorporated at various levels in future process-control systems, as well as in systems for mechanical translation and the automatic recognition of speech sounds and visual patterns.

Simple discontinuous learning machines

Ashby's homeostat (*1*) might be regarded as a kind of learning machine. It incorporates four pivoted magnets, actuating four liquid potentiometers. The output signals from the potentiometers, suitably amplified, can be connected in a very large number of ways to coils influencing the magnets. Some patterns of connexions lead to stable behaviour of the assembly, others to instability. The homeostat incorporates an arrangement for altering the connexions randomly until stability results; the connexions are then left alone. Stability can be achieved under a wide variety of conditions, as for instance when two of the pivoted magnets are connected by a light rod, or when the connexions to some of the coils or potentiometers are reversed. Ashby uses the term *ultrastability* to describe the kind of behaviour shown by the homeostat.

The homeostat probably should not be described as 'learning', since it only stores the pattern of connexions it found to produce stability the last time it readjusted to a change in external conditions. Having once altered the pattern, it is unable to come back to it if the same external conditions recur, except by further random searching.

Behaviour which more clearly embodies learning principles is shown by Uttley's conditional probability computer (*2, 3, 4*). This machine is not inherently goal-seeking, but can be made so with the help of additional circuitry, as discussed by Andrew (*5*). The computer itself has a number of input channels, each of which can be activated in an all-or-nothing fashion. Statistical information is stored concerning the patterns of activity which occur in these channels, and under certain con-

ditions the computer may make an 'inference' of activity in a channel which has not, in fact, been activated. For example, if channels A, B and C have been simultaneously activated a sufficient number of times, activation of A and B only will produce an inference of activity in C. The necessary condition is that the conditional probability of C, given A and B, should be above a predetermined threshold value.

The computer works by counting (in capacitors) the numbers of occurrences of particular groups of active channels. When channels A, B and C are activated together, the counters affected are those corresponding to the groups A, B, C, AB, BC, AC and ABC. Then the conditional probability of C, given A and B, is computed as the ratio of the count on the ABC counter to that on the AB counter.

The computer simulates various features of animal learning, and in particular it can model a Pavlovian conditioned reflex. Pavlov showed that if, on a sufficient number of occasions, a bell is sounded shortly before an animal is given food, it begins to make the response which is normally evoked by food (namely salivation) when the bell is sounded alone. Two channels of the conditional-probability computer can be labelled 'bell' and 'food' respectively. Then when the two have been activated together a sufficient number of times, 'bell' alone will produce an inference of activity in the 'food' channel, and this is all that is necessary to simulate a conditioned reflex. Other more complicated simulations of animal learning are also possible.

Somewhat similar behaviour to that shown by Uttley's machine can be produced by other means. For instance, the circuits of Fig. 1 generate a voltage which may be taken as a running measure of the conditional probability of B given A. It is arranged that S_1 operates and drops back again every time A occurs, and S_2 is in its upward position if B has also occurred, and down if B has not occurred. The capacitor voltage clearly rises to V_o if A is always accompanied by B, and falls to zero if A is never accompanied by B (see Andrew (5)). The voltage on the capacitor on the left of Fig. 1a or b, following the nth occurrence of A is given by

$$V_n/V_o = (1 - r)(\delta_n + r\delta_{n-1} + r^2\delta_{n-2} + \ldots .)$$

where $\delta_i = 1$ or 0, according to whether or not the ith occurrence of A was accompanied by an occurrence of B.

Another arrangement which indicates the degree of association of two types of event A and B has been described by George (6). This is much more complex than the circuits in Fig. 1 but is built entirely from elements which are like the idealized nerve-cells discussed by McCulloch and Pitts (7). Consequently the device is of special interest as a possible model of part of the nervous system. The operation of the George system is mathematically different from that of the circuits of Fig. 1, since his circuit has a definite number of stable states. The effect of a conjunction of A and B is to transfer the circuit to the state next highest to that previously occupied, while that of a disjunction (A without B, or B without A) is to transfer it to the next lowest. When the highest state is reached, further conjunctions have no effect, and similarly in the lowest state further disjunctions have no effect.

MacKay (8, 9) has discussed possibilities for self-organizing systems containing a large number of units with interconnecting links which behave statistically, with the probability of effective transmission of activity through a link from one unit to another depending on

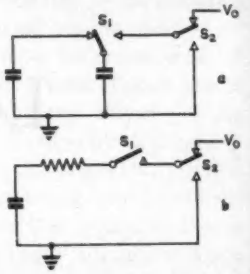


Fig. 1 Two simple circuits for computing a 'running value' of conditional probability

the past activity of the link. The links must incorporate some element which collects statistical information concerning its past activity. George's circuit or those shown in Fig. 1 could be used. MacKay gives a circuit incorporating thyratrons and hoppers containing ball bearings; this, of course, is intended for demonstration only.

The need for interpolation

The systems discussed by Uttley, George, Ashby and MacKay all have two-valued signals in their input and output channels, even though continuous variables may be computed internally. The restriction to two-valued signals is a serious difficulty when the possibility of practical applications is considered. Possible applications to process control have received particular attention; for these it is certainly necessary that the control system, and the learning device incorporated in it, should take account of quantitative information.

A system which accepts two-valued signals can, of course, be made to handle quantitative information with any required accuracy simply by allocating a sufficient number of yes-no channels to represent each continuous quantity. However, such an adaptation of one of the above systems could only operate by learning separately how to deal with every situation which could be discriminated with the accuracy of measurement incorporated. It is obvious that the learning process would be much more effective if the learning could be 'smeared over' from one situation to others with some degree of similarity. In other words, for many applications a learning machine must exploit the continuity of its environment. To do this it must interpolate between states of the controlled system, and there seems to be no simple way in which the systems described above can be made to do this. The simplest way of doing it seems to be to deal with quantitative signals right from the start.

Adaptive devices which handle quantitative signals have been described by numerous workers, and have been reviewed by Aseltine, Mancini and Sarture (*10*). These devices fail to justify the term 'learning' in much the same way as did Ashby's homeostat. They are able to adjust controlled variables to values which give optimum performance under a particular set of conditions, but they do not remember what values were optimal, so as to return to them immediately if the same set of conditions occurs again. Further developments are possible, however, which do appear to justify the description of learning. Examples of these devices are the controller described by Draper and Li (*11*), and another termed the Opcon, which has been produced by Westinghouse and is described by Burt and Van Nice (*12*). The former adjusts the ignition timing and the proportions of the gas-air mixture supplied to an internal combustion engine. The aim of the adjustment is to maximize the power developed by the engine. The Opcon similarly adjusts any two controlled variables so as to maximize any other quantity which is a function of them.

The essential requirement of a learning device is presumably that its response to a particular set of conditions in its environment should be favourably influenced by stored information concerning previous occurrences of the same or a similar set of conditions. This requirement can be met by devices in which the controlled variables are functions of quantities measured in the controlled system, if the functional relationship is modified in an adaptive fashion. If sufficient flexibility is provided the relationship should become such that the controlled variables remain close to optimal values over a wide range of states of the controlled system.

A feature which can greatly increase the flexibility of the adaptation is the facility of modifying the *form* of the functional relationships as well as finding optimal values for parameters incorporated in them. Some principles which should make this possible have been suggested by the author (*5*). It is debatable whether or not devices with this feature would simulate any kind of animal learning, but it is certainly true that they can show behaviour which would readily be admitted as 'learning' if it *were* shown by an animal.

Complex learning systems

Several workers, including Pask (*13*) and Stafford Beer of the United Steel Companies have considered learning machines of a degree of complexity which would not be feasible using conventional electronic components. They tend to be interested in developing self-organizing systems for economic planning and industrial management rather than for process control. An industrial organization with its personnel and machinery, as well as its customers and suppliers, is an extremely complex system of interacting entities. It is, in fact, more like a biological organism than the kind of mechanism with which control engineers are usually concerned. It has been suggested that a system to take control in industry should also be similar to a biological system and should consist of a great many elements, not necessarily reliable in themselves, produced by what Pask terms a 'growth process' from undifferentiated material. Beer has experimented with a swarm of magnetized daphnia as a self-organizing system; Pask has passed currents through an electrolytic solution in such a way that metallic threads are deposited on the bottom of the container. These threads influence the current pathways, and their development depends on the applied currents. A large number of electrodes can be inserted in the tank, some with current applied and others sampling the potential field, and a complex system is built up.

The system of threads can be 'rewarded' and thereby encouraged to grow when it is tending to produce favourable results. The reward consists of an increase in the total current available to the system, or of the metallic ions available for deposition. Hence the growth process can readily become goal-directed.

Other schemes for learning machines inspired by biological studies have embodied networks of electronic 'model neurons' (or nerve cells). Von Foerster (*14*), Willis (*15*) and Rosenblatt (*16, 17*) have used this approach, the last-named working mainly with systems simulated on a digital computer. Rosenblatt is concerned with learning machines for pattern recognition, and his networks contain receptor units, association units and response units, of which the association units are modified in the course of learning. He has published experimental results from the computer simulations, in which the receptor units were considered to form a retina and the systems were trained to recognize capital letters. However, the simulated networks in these experiments had no interconnexions between association units, but only connexions of these to receptor and response units. It is difficult to see how such networks can do anything more than rather elaborate template-fitting.

It seems unlikely that complex learning systems will find practical application for some time to come, though it is dangerous to be dogmatic. The argument is sometimes advanced that such systems must work because the nervous systems of animals appear to be similar and they certainly show useful behaviour. This is a rather weak argument, however, since the changes which constitute learning in a nervous system are not at all well understood, and consequently it is impossible to know that any artificial system simulates a nervous system in this respect.

Model-adjustment versus control-function adjustment

In designing a learning machine to control a system external to itself, two approaches are possible. The learning machine may or may not incorporate a representation of the external system. The methods discussed up to now have not involved a representation, and may be said to work by direct adjustment of the control functions. Kalman's (*18*) self-optimizing controller re-

presents the external system by an equation with adjustable parameters and the learning process operates purely to adjust this to represent the external system as accurately as possible. Then the optimum control function

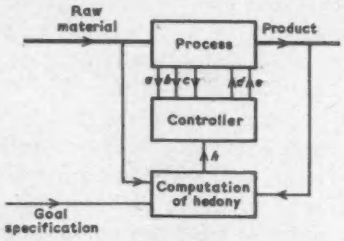


Fig. 2 A process controlled by a learning controller. The quantities a, b, c are measured by transducers in the process, d and e are controlled variables, and h is the hedony, or degree of goal achievement

is derived from this mathematical model by a straightforward, non-learned computation.

If the goal-specification of a controller is not to be the same at all times, the model-adjusting type of operation would seem to be preferable if the behaviour of the external system is not too complex to permit it. With this type of operation the adjustments made in the course of learning are not referred to a particular goal and the model is relevant to the achievement of any goal.

It might appear at first sight that the type of controller which adjusts control functions could only respond to changes in goal-specification by re-learning its control policy every time the goal specification was changed. This is not necessarily so, however, if the signals which specify the goal are incorporated in the control functions as well as being used to compute hedony (see Figs. 2 and 3). (The term ' hedony ' is used following Selfridge (*19*), to denote the degree of goal-achievement.)

Move-and-stick versus correlation

A number of self-optimizing systems operate by making some experimental change in conditions, waiting to determine the effect on the process, and then retaining the change if favourable or rescinding it if unfavourable. The Westinghouse Opcon works in precisely this

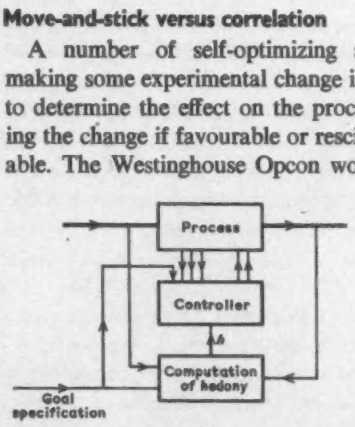


Fig. 3 Another process controlled by a learning controller, but with the specification of the goal included in the controller-input data

way, and several other systems embody variations, including the peak-holding type of controller described by Draper and Li. The principle may be described as *move-and-stick*.

The above principle cannot be applied where the process is subject to some unpredictable disturbance unless the effects of the disturbance are slight, or slow compared to the time which elapses between the occurrence of a change in operating conditions and its effect on the process (as indicated by the measure *h* in Fig. 2). When the effects of random variations are serious, it is impossible to know whether a change in hedony results from them or from an applied change in the operating conditions.

When a large disturbance is present, optimization must depend on a series of fluctuations instead of one experimental move. Then the correlation between the fluctuations and the hedony can be computed, and a change made in the operating conditions if this measure is statistically significant. This form of operation has been discussed elsewhere (*5, 20*). Kalman (*18*) also uses correlation.

Somewhat different considerations apply if the statistical data governing the adaptive changes are based on a period of recording of the relevant variables. This is only possible, of course, for the model-adjusting type of operation, in which the experimental variations do not affect the actual process. There is no need, in this case, to make repeated fluctuations and to compute correlations, since the statistical data can be derived with perfect consistency.

The consistency may be misleading, however, if the process was affected by an unpredictable disturbance during the recording period. The effects of such disturbances could be detected by letting the model be adjusted according to two or more separate periods of recording and comparing the parameter-values reached. Gabor (*21*) employs magnetic tape recording in his self-optimizing filter.

Learning-to-learn

In designing a learning system of any complexity, a number of rather arbitrary decisions must be made about its detailed operation. For instance, values must be chosen for the time-constants of smoothing of whatever statistical quantities are collected (correlations, conditional probabilities or others), and in the case of correlation a decision is needed as to the level of statistical significance to be reached before the machine takes the indication into account. The choice of values for these quantities must be somewhat arbitrary because the complexity of the system makes the mathematical determination of optimal values virtually impossible, particularly since they depend on the nature of the process to be controlled. The speed and effectiveness of the machine's learning, however, are greatly affected by the values chosen. In fact, the design of learning machines is precisely the kind of intractable problem which it is hoped to by-pass by their use. It seems likely, then, that there will eventually be no fixed values incorporated for many of the parameters which control adaptive procedures. The internal organization of learning machines will be subject to adaptive modification. They will, in fact, learn to learn.

As part of the work on learning machines connected with the National Physical Laboratory it is hoped to control a process such as a distilla-

tion column with a controller developed from Uttley's conditional-probability computer. The difficulties discussed under the heading *The need for interpolation* became apparent at an early stage of this project, but there are some ways in which they may be circumvented. A suggestion by Uttley, elaborated by Rees (*22*), is to let the operating conditions of the process be optimized by a fairly simple hill-climbing system similar in operation to the Opcon, but to let the searching strategy of this be developed in a trial-and-error fashion by a conditional probability system. The complete system would then 'learn to learn' in a rather elementary way.

Self-organization and concept-formation

Self-optimizing systems which work by adjusting values of parameters in control equations are often thought to be uninteresting and only capable of a very elementary form of learning. This need not be so, however. In the kind of system discussed by the writer elsewhere (*5, 20*), as well as in Gabor's (*21*) system, polynomial functions are used to provide functional relationships which can be optimized by altering the coefficients of the terms. By incorporating enough terms of sufficiently high order, any functional relationship can be approximated in this way. It is possible to incorporate in the learning machine a means of deciding which polynomial terms could profitably be added to the control equations, and also which terms already in use are serving no useful purpose. Hence the system can incorporate a degree of self-organization, by which the available computing circuitry is allocated in the best possible way. It is also possible for the controller to have available to it information channels which initially are not known to be relevant to the control task. If they are relevant the controller can learn to incorporate them in the control functions.

Systems of this type can also show the kind of behaviour which Pask (*13*) terms 'concept formation'. A concept is some function of the input data which can profitably be abstracted. The self-optimizing system may contain sections which work towards a sub-goal which is not the main goal of the complete controller. A sub-goal in the control of a distillation column, for instance, might be to maintain a particular temperature distribution in the column, although the overall goal is to maximize the profit of the operation. The controller can be made to form and modify its own sub-goals; in this case a sub-goal is essentially a concept.

Sequential learning machines

The type of learning machine discussed above could conceivably learn to perform a sequence of operations or to apply a number of different control functions in sequence. A measure of the time elapsed since some event, or the information that a particular goal had been achieved, could be incorporated with the other input data in the control functions, and could produce sequential operation.

However, sequential operation can more readily be produced by two other kinds of learning machine. Deutsch (*23*) has devised a machine to imitate the behaviour of a rat running a maze; this is capable of recognizing the point in the maze which has been reached and deciding which should next be sought. It is capable of modifying its behaviour, while still utilizing its previous learning, to take advantage of short cuts which are introduced in the maze.

A different kind of sequential learning machine has been described by Donaldson (*24*). This learns a sequence of events, and the time-intervals between them, if the sequence is repeatedly presented to it. It can remember several sequences at the same time, and can reproduce any of them when given the start of it. It could, for instance, remember musical tunes, complete with time-intervals between notes.

The combination of these sequential devices with the previously-discussed learning machine should produce very powerful control systems. Work on learning machines to date has only scratched the surface of what is possible.

Acknowledgement

I am indebted to the Director of the National Physical Laboratory for permission to publish this article.

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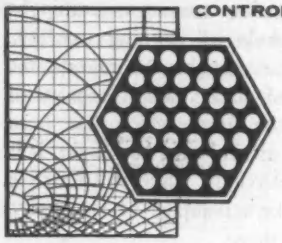


PART A

'To achieve the higher temperatures required we are forced to use beryllium or stainless steel as a canning material; either course increases fuel element cost. This must be compensated for by achieving higher ratings and higher burn-ups. . . .'

'. . . the problems of reactor stability and control . . . become more acute when higher ratings and burn-ups are used'

Sir Christopher Hinton, Chairman, C.E.G.B. at a Royal Society Tercentenary Lecture, London, 20 July, 1960

Automatic control of power reactor systems

by **J. H. BOWEN**

U.K. Atomic Energy Authority

IN FIGURE 1 IS SHOWN A TYPICAL EXAMPLE OF THE power-generating system to be considered, in which a coolant fluid is passed through a nuclear reactor (the temperature of the fluid rising from T_1 to T_2), and through a heat exchanger where, in the steady state, it gives up to a working substance the heat gained in the reactor. The working substance is expanded, e.g. in a turbine, and is then cooled, e.g. in a condenser, and pumped back for re-use. Some example of reactors to which this diagram applies are quoted in Table 1.

Power and temperature, which are most important in the control of the reactor, are controlled by movement of the reactor **control rods,** which are made of neutron-absorbent material, and by adjustment of the mass-flow rate, W lb/sec, of the primary coolant, i.e. by the circulator speed N rev/sec, and also by the steam pressure generated, P_S, determined by the setting of the throttle valve. To improve thermodynamic efficiency, the designer usually tries to operate his plant at the highest possible temperature. It often happens that the temperature of the fuel is the limiting factor, so part of the control problem is to regulate this temperature at the selected value with minimum and clearly specified deviations.

It should be appreciated that a primary function of **fuel cans** (which are infissile sheaths around the fissile fuel) is to contain the fission products. If a small fraction of these products were to escape, heavy shielding against nuclear radiation would be needed round every part of the circuit and maintenance would be difficult. Indeed some reactors (in which the cans also prevent corrosion of the fuel by the coolant), would be impossible to operate, for the detection of fission products even in small amounts is a sensitive indication that the hermetic sealing of the cans has failed; after heavy contamination of coolant with fission products the required sensitivity would be lost, and corrosion could not be detected.

For these reasons good measurement and control of fuel-element temperature is very important. One difficulty is that the temperatures occurring in the system, even of a particular component, often cover a wide range. For example, a temperature gradient of several hundreds of °C between the hottest and coolest fuel elements would normally be expected at full power.

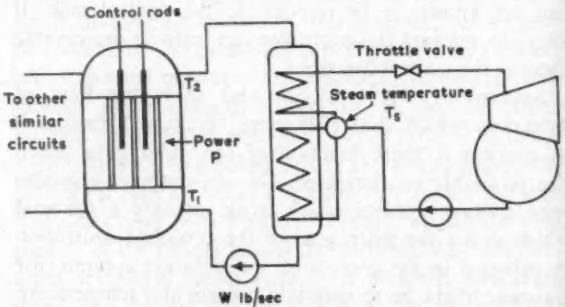


Fig. 1 Power-producing reactor system

The other important variable requiring control is the reactor power, P. Ultimately, of course, it is the output power of the system which is of interest, e.g. the output power at an alternator, or at the propeller-shaft of a ship. This differs from the reactor power by losses in the system, e.g. in power supplied to coolant pumps and in steam pressure drops, but these may be allowed for by a simple calibration between corresponding inlet and outlet powers. Time lags are not so easily allowed for. A change of reactor power is effected by changing the depth of insertion of control rods and coolant cir-

culator speeds; these, and the subsequent reactor-power changes, involve time lags, and there is a further time lag in transferring the resulting temperature-changes through the heat exchangers before the desired change in output power appears. If necessary, overall control may be stiffened by an automatic control loop from output to input. The first electricity-producing power reactors will probably operate on almost continuous full load, so that this aspect of automatic control will hardly arise. As the contribution from nuclear stations becomes an increasing proportion of the grid supply, however, the nuclear stations will have to be controlled to some extent to match the load demanded; this may either involve an instruction from central grid control, or a local automatic control regulating the busbars to a fixed frequency. It will appear below that the main lag is likely to be in the heat exchangers. This time lag is a few minutes, so that even if continuous control is essential, it is unlikely to be necessary to resort to closed-loop control over power in grid electricity-production applications. In the case of mobile (marine) applications, time lags of minutes will be unacceptable. Even here, however, the system response can be improved by increasing the 'demand side capacity', e.g. by the capacity of the steam reservoirs, so that closed-loop power control may still be avoided.

Usually it is not possible to arrange to control power and temperature independently. The interactions between them will be illustrated later in this article. There are certain superimposed requirements for reactivity control which appear in effect as disturbances in the power-temperature control loops. The effect of the reactor control rods (*1*, *2*) is to vary the multiplication factor k. The value of k is determined not only by the position of the reactor control rods, but also by: the temperatures of the different components of the **reactor core** (the assembly ot fuel, moderator, and control rods in which the nuclear reaction occurs); the power level, which determines the concentrations achieved by certain isotopes having a high affinity for neutrons in the core; and the degree of **irradiation** (loosely called **burn-up**) of the fuel. The control system must (a) allow these changes to be compensated by the control rods, (b) usually allow temperature to be regulated at a chosen level, and (c) allow power to be varied over the required range without excessive time delays. In addition, some reactor systems require automatic control over the distribution of power within the core. A variation of temperature can change the value of the multiplication factor, either in a positive or negative sense, depending on the core design and the isotope concentrations existing at the time. The value of the change in k per unit change in temperature of the component concerned, is known as the **temperature coefficient.** If this is positive, a local variation in temperature—e.g. uneven cooling in some channels of a reactor—causes an increase in k which, although local, causes the power all over the reactor to tend to increase. This is because the extra neutrons produced in the high-temperature region spread out over the reactor, causing a general increase in power. This power deviation would be detected and corrected by the normal power controller, which would cause control rods to move in to absorb the extra neutrons, but not necessarily in the precise region of the reactor where the high value of k exists. Overall, the power could thus be restored to its desired value; but the region which was originally overheated would be left with an increased share of the load, this being compensated by a low power elsewhere, generally in a region oppositely placed with respect to some axis of symmetry of the reactor. Thus a positive temperature coefficient enhances any unbalanced temperatures which may exist, increasing the

TABLE 1

LOCATION	THERMAL POWER MW	MODERATOR	COOLANT
Calder Hall, U.K.	200	Graphite	CO_2 gas
Stage-I† Reactors (Bradwell, Berkeley, etc.), U.K.	350	Graphite	CO_2 gas
Shippingport, U.S.A.	230	Water	Pressurized water
Dresden, U.S.A.	625	Water	Boiling water*
Dounreay, U.K.	60	—	Liquid sodium

† 'Stage 1' refers to the U.K. nuclear power program.

* In a boiling-water reactor power system, the steam may be passed directly to a turbine and separate steam-raising units may be unnecessary.

NOMENCLATURE

W	Mass flow rate of primary coolant, lb/sec
N	Circulator speed, rev/sec
P_S	Steam pressure, lb/in²
k	Neutron multiplication factor
δk	$(k-1)$ i.e. excess multiplication factor, or reactivity
a	Temperature coefficient of reactivity
P	Reactor power, MW
T_1	Coolant temperature at reactor inlet
T_2	Coolant temperature at reactor outlet
T_{2E}	Error temperature in blower-speed loop and control-rod loop = demanded outlet gas temperature $-T_2$
T_{1E}	Error temperature in steam-pressure control loop = demanded gas temperature at reactor inlet $-T_1$
A_n	Amplitude coefficient in equation 8
l	Mean lifetime of prompt neutrons
β	Fraction of emitted neutrons which are delayed
β_i	Yield of delayed neutron group of type i
λ_i	Decay constant of neutron group of type i
j	Operator $\sqrt{-1}$
R_1	Resistance to heat flow, reactor fuel element to coolant, °C/mW
R_2	Resistance to heat flow out of core, °C/mW
R_3	Resistance to heat flow, coolant to moderator °C/mW
C_1	Thermal capacity of fuel elements
C_2	Thermal capacity of coolant
C_3	Thermal capacity of core structure (usually moderator)
τ_1, τ_2, etc.	Time constants R_1C_1, R_2C_2, etc.

temperature error above that which would have occurred in the absence of a temperature coefficient, in the ratio:

$$A = \left(1 - a\frac{\partial T}{\partial k} - K_x\right)^{-1}$$

where

a is the combined effective temperature coefficient for moderator and fuel

$\partial T/\partial k$ is the ratio of the increase in temperature to the reactivity producing the increase, assuming the system to have zero temperature or xenon reactivity coefficients. In other words this is an 'open loop' ratio with no xenon or temperature feedback

K_x is the local increase in k which would be expected due to xenon poisoning, divided by the original (local) increase in k. Again, it is the 'open loop' value.

Both $\partial T/\partial k$ and K_x are sensitive to the reactor size, which affects the 'amplification', because if the reactor dimensions are small (in proportion to the **neutron migration length,** M, which is a length representative of the total distance travelled between birth and death), neutrons from the overheated region strongly affect all parts of the reactor, and it is more difficult for one part to 'run away' at the expense of another. If the amplification is unacceptably large, the remedy is to arrange for local control over k by a number of the control rods. Local automatic controllers detect local unbalance of power or temperature and move the local control rod accordingly.

The final requirement of a reactor control system is that it should be safe, meaning that it should be properly matched to an efficient and proven protective system, and should not require to invoke this protection in any way that can be reasonably avoided. Apart from the obvious requirements of sturdy design and failure-to-safety, the main implications are in the choice of the range of k controlled by the various individual members of the control-rod system, and the rate at which each is capable of varying k. The larger the rate of change allowed for k, the bigger the deviation of k which occurs during the inevitable time lags between detection of the deviation (through its effect on power or temperature) and protection by the operation of the shut-off feature. This may take the form of an overriding signal to the control rods in the shut-down sense, the movement now being at high speed. If control-rod speeds in the direction of increasing reactivity were unwisely chosen to be too high, it would be possible for the power and temperature overshoot to cause damage. Because the overshoot depends upon the starting conditions for the transient—whether from full power or 'shut-down power', and whether the latter includes a neutron source or not (2), it is not easy to fix an upper limit for the control-rod speed, the usual approach being to select the minimum speed required to counteract the anticipated disturbances to k and to check that this appears to have a good safety margin as defined above. The control rods concerned with regulation of power distribution are likely to present some difficulty. Part of the reason, as will be seen later in this article, is that comparatively high control-rod speeds are required for smooth regulation of power; and although the rate of change of k required for each separate automatic controller is not such as to cause concern, all the rates added together could be troublesome. It may be possible, by suitable segregation of the units, to ensure that even under fault conditions, simultaneous addition of k is not possible. A further precaution is to limit the range of k-addition available to each unit. This can be done provided that the units are backed up by an integral corrective action, in which k is added slowly to restore over a long period the 'saturable' controller to its working range.

The mechanisms driving the control rods must therefore provide a limited upper rate of reactivity addition; and below this for speed control as required by the design of the control loop. They must be capable of locking the control rods without permitting creep; and for shutting down the reactor they must provide controlled speeds plus a shut-off mode of action which must be fast and reliable.

Analysis of stability of power reactor

For stability analysis, an approximate treatment by linearization of the equations is suitable, leading to the application of familiar servo-mechanical methods. It is often convenient to work in terms of the inlet and outlet coolant temperatures, these being the average mixed temperatures in the inlet and outlet coolant headers. The relation between these and any other plant temperatures which may be required, e.g. of the fuel element, may be solved by normal heat-transfer equations not involving stability analysis.

Consider conditions in the reactor.

$$T_2 = f_1(T_1, W, P) \qquad (1)$$

Where f_1 represents some function which we do not need to establish completely. Then approximately

$$\delta T_2 = \frac{\partial f_1}{\partial T_1}\delta T_1 + \frac{\partial f_1}{\partial W}\delta W + \frac{\partial f}{\partial P}\delta P \qquad (2)$$

The differential coefficients $\partial f_1/\partial T_1$, etc., are themselves functions of the variables P, T, W etc., and would normally be established at the working point of interest, and over a small range are assumed to remain constant.

Considering the steam-raising units

$$T_1 = f_2(T_2, W, T_s) \qquad (3)$$

$$\delta T_1 = \frac{\partial f_2}{\partial T_2}\delta T_2 + \frac{\partial f_2}{\partial W}\delta W + \frac{\partial f}{\partial T_s}\delta T_s \qquad (4)$$

In addition the reactor power is itself a function of the applied reactivity δk determined by the control-rod position, and the effect on reactivity of temperatures.

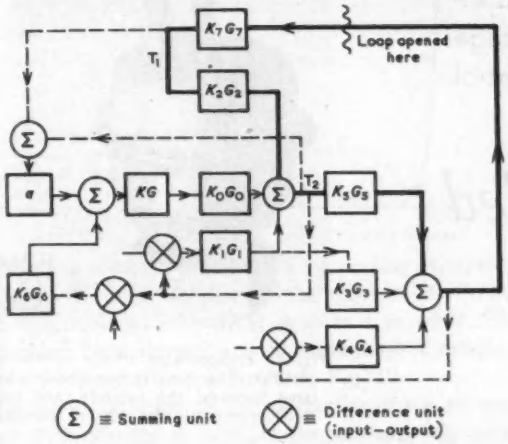


Fig. 2 Control diagram. a = temperature coefficient. KG = $P/\delta k$. $K_0G_0 = T_2/P$. $K_1G_1 = (T_2/T_{2E})$ due to blowers. $K_2G_2 = T_2/T_1$. $K_5G_5 = (T_1/T_{2E})$ due to blowers. $K_4G_4 = (T_1/T_{1E})$ due to steam pressure. $K_5G_5 = T_1/T_2$. $K_6G_6 = k/T_{2E}$. K_7G_7 = gas transport lag

These relationships may be represented in the form of a control diagram (Fig. 2). Some of the lines shown are inherent in the plant design, whilst others are at the disposition of the control system designer. The choice of the most suitable mode of operation would emerge from a series of studies of the characteristics of alternatives, of which only one is discussed here. Referring to Fig. 2, circulator mass flow W and steam-side temperature T_s, are shown with local feedback loops (K_1G_1 and K_4G_4 respectively) regulating T_2 and T_1 at constant values. Particularly for large gas-cooled reactor systems, there is an advantage in keeping constant the general structure temperatures which are largely determined by the coolant temperatures. The effect of temperature on reactivity is shown as a feedback proportional to mean coolant temperature, i.e. to $(T_2 + T_1)$. This is approximately true of a water-cooled water-moderated reactor in which the coolant fluid participates directly in the neutron economy. In a Stage-1 reactor the temperatures of fuel and moderator have separate effects on reactivity, whilst coolant temperature has little effect. In this case further transfer functions could be included to represent the relation between coolant temperature and the temperatures affecting reactivity.

The inherent feedback due to temperature coefficient is reinforced by an automatic control loop (K_6G_6) in which control rods are moved to eliminate temperature deviation T_{2E} of T_2 from its demanded value.

The transfer functions of the elements represented in Fig. 2 may be combined in the usual way, leading to the overall open-loop transfer function

$$\frac{T_1'}{T_1} = \frac{K'G' + K_2G_2}{1 - K'G' + K_1G_1 + K''G''} \cdot \frac{K_5G_5 + K_4G_4}{1 + K_4G_4} \quad (5)$$

where $K'G' = (a)(KG)(K_0G_0)$ (6)

and $K''G'' = (K_6G_6)(K_0G_0)(KG)$ (7)

Illustration of forms of individual functions

KG denotes the Laplace transform of the power output of the reactor as a function of the input reactivity. This transfer function may be calculated (*1*). The result is non-linear in that a sinusoidal input of reactivity δk at frequency ω excites a train of harmonics related to each other by equation 8:

$$A_m = \frac{\delta k(A_{m-1} + A_{m+1})}{2jm\omega \left\{ l + \sum \frac{\mu_i \beta}{jm\omega + \lambda_i} \right\}} \quad (8)$$

where the A's are the amplitudes of the harmonics of order m, l represents the prompt mean neutron lifetime. β is the delayed-neutron fraction, whilst μ_i and λ_i are the yields and decay constants of the respective groups of delayed neutrons.

The amplitudes of these harmonics rapidly diminish if the reactivity variation is small, which is assumed to apply in the present analysis. Considering only the fundamental response

$$KG = \frac{P}{\delta k} = \frac{P_o}{j\omega \left(1 + \sum \frac{\mu_i \beta}{j\omega + \lambda_i} \right)} \quad (9)$$

P_o is the mean power level about which the oscillation is performed.

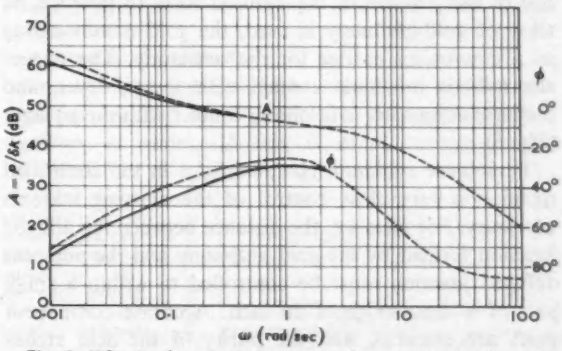


Fig. 3 KG, the frequency response of a graphite-moderated thermal reactor

It has been suggested in (*1*) that a workable approximation to this, employing the constants appropriate to a Stage 1 reactor, is

$$\frac{P}{\delta k} = \frac{30(1 + 5{\cdot}7\, j\omega)P_o}{j\omega(1 + 0{\cdot}2\, j\omega)} \quad (10)$$

The frequency diagrams for equations 9 and 10 are shown in Fig. 3. The similarity between the reactor and an integrator will be noticed. If reactivity is different from zero, power continues to increase or decrease. At very high and very low frequencies the phase angle is −90°; in between it rises towards zero owing to the phase lead imparted by the prompt, as opposed to delayed, neutrons.

To be continued

PART 2

Uses include a.c. or d.c. switching, d.c.-a.c. or d.c.-d.c. conversion, variable d.c. supply, surge-voltage suppression, dynamic braking and welding control

The silicon controlled rectifier

by **A. J. SADLER** *and* **P. A. TURNER**

A.E.I (Rugby) Ltd.

Fig. 8 Encapsulated silicon controlled rectifier. The base is the anode, the large terminal the cathode, and the small terminal is the trigger electrode

Last month we described the mode of operation, and then went on to consider processes of manufacture. We showed how a p *impurity is diffused into an* n *slice of silicon to create a* pnp *structure, and how sections are taken to find where the* p *and* n *impurities balance.*

The fourth layer (*n* type) is produced by alloying a suitable *n* impurity, such as arsenic or antimony, into one of the *p* layers of the diffused slice. In practice, an alloy of gold-antimony is used, the gold merely acting as a convenient carrier for the antimony. The trigger electrode is in ohmic contact with the p_2 layer, and the base connexion is in ohmic contact with the p_1 layer (Fig. 5).

To achieve optimum characteristics in the controlled rectifier, a very close control of the alloying stage is necessary. For instance, the distance between the alloyed junction formed by the gold antimony and the adjacent diffused junction must be controlled to within a small part of a thousandth of an inch. Accurate component parts are essential, and the purity of the acid etches which are used to clean the various components before alloying must be carefully controlled. If the gold antimony penetrates too far the controlled rectifier will have a 'permanently switched' characteristic. If the penetration is too small, very high triggering currents will be required. The alloying may be carried out under vacuum or inert gas. Both the temperature and time of the alloying cycle are closely controlled.

After alloying, the basic unit is ready for its encapsulation and is subsequently hermetically sealed. The encapsulation is shown in Fig. 8.

Characteristics of controlled rectifiers

Fig. 9 shows the current-voltage characteristic, measured across the main contacts of a controlled rectifier. The characteristic illustrates some of the parameters which are important in the use of the rectifier as a switching element.

The break-over or switching voltage V_{BO} is a function of geometrical design, and the basic properties of the four regions p_1, n_1, p_2, n_2. For a multiplicative switch, this voltage depends on both the resistivities of regions n_1 and p_2 and the gradient of impurities through junction B, and adjustment of these two factors permits a variation of V_{BO} to be obtained. However, at the higher voltages, surface leakage paths across junction B cause switching below break-down, and in spite of careful surface treatments before encapsulation, limit the values of V_{BO} obtainable.

The voltage drop in the switched-forward direction is an important factor since it is a measure of the power dissipated in the device when working. As the device is affected by an increase in temperature, the power

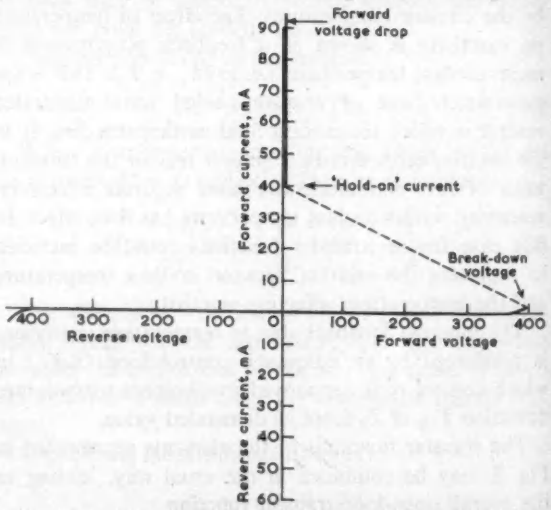


Fig. 9 Electrical characteristic of a controlled rectifier with no trigger current, at room temperature. In the reverse direction, little or no current is passed up to about 400 V, while in the forward direction up to about 400 V can be withstood before break-over into the low-impedance state

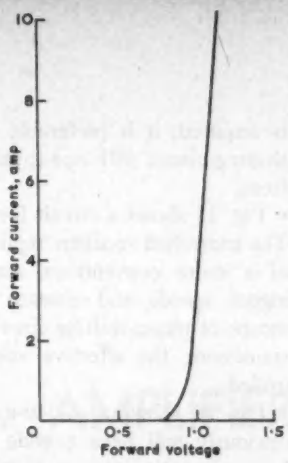


Fig. 10 Switched-forward characteristic of controlled rectifier. In the forward conducting state the device offers very low impedance

dissipation controls the amount of cooling equipment necessary. Current densities of the order of 100 A/cm² are obtainable at a potential drop of 1 to 1·5 V. This is comparable with rectifiers of similar area. A switched-forward characteristic is shown in Fig. 10.

Owing to variations in the properties of the *pn* junctions with changes in junction temperature, V_{BO} varies markedly as shown in Fig. 11. Up to temperatures of the order of 130°C, very little change in V_{BO} is noted. A further rise in temperature causes a rapid decrease of V_{BO} to zero at about 180°C.

The above characteristics are those of either a two-terminal or a three-terminal device with the third contact open-circuited. The effect on V_{BO} of a bias current I_t flowing through an outer junction in a forward direction is shown in Fig. 12 and is similar to an increase in temperature, the current below V_{BO} increasing and the break-over voltage remaining constant up to a given value of I_t before showing a rapid decrease to zero. The bias current I_t necessary to reduce V_{BO} to zero is the important factor in the use of these devices as controlled rectifiers, and is mainly dependent on the geometry of the design. Values of this parameter are found to vary from 10 mA to 100 mA. I_t varies with increasing temperature and falls to half its original value for a change in temperature from 20°C to 120°C (Fig. 13). The overall forward characteristics of the device for various values of I_t are plotted in Fig. 14.

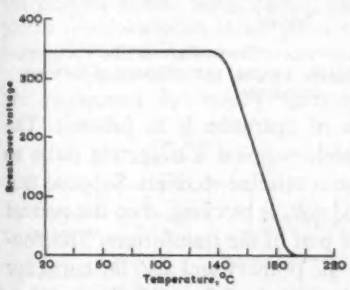


Fig. 11 Variation of break-over voltage with junction temperature. The higher the voltage that can be withstood, the better the efficiency, so finning is used to keep the junction temperature down to about 120°C. Above this the break-over voltage starts to fall rapidly

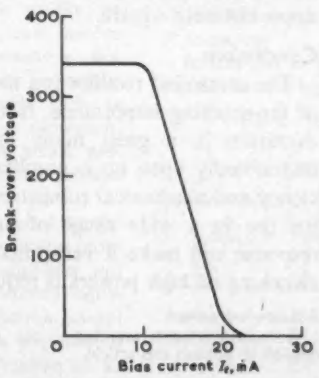


Fig. 12 Variation of break-over voltage with bias current through the third electrode. The effect illustrated here makes it possible to control current from a d.c. source, but Fig. 13 shows that such a control would be sensitive to temperature

The inverse characteristic of the device shows a similar variation with temperature as a simple *pn* junction rectifier, the inverse current increasing considerably with temperature.

Applications

The controlled rectifier is comparable to a thyratron, which it can replace in many applications. Its uses include a.c. or d.c. switching, d.c.-to-a.c. or d.c.-to-d.c. conversion, variable d.c. supply, surge-voltage suppression, dynamic braking, and welding control.

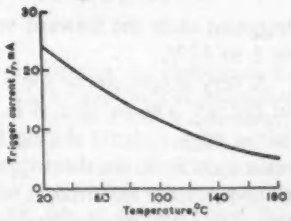


Fig. 13 Variation of trigger-current requirement with temperature. It is necessary to use a sharp-edged pulse of control current, or the control point will vary as the temperature of the device varies

When compared with the thyratron the controlled rectifier has several advantages:

1. A very low forward voltage drop—about 1 V compared with 8 V or over in the case of thyratrons—resulting in high efficiency.
2. Lower recovery times—only a few microseconds compared with 100-μs de-ionization time in the case of the thyratron.
3. Absence of a filament.

For working voltages higher than the existing ratings per rectifier, it is possible to connect controlled rectifiers in series. If this is done, voltage-sharing resistors and capacitors must be placed across each unit and there must be provision for electrically isolated, but identically timed, trigger supplies for each rectifier. This can be done by means of a small pulse-type transformer with a number of secondaries.

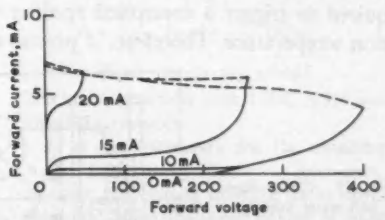


Fig. 14 Forward characteristic of a controlled rectifier for various values of bias current passing through the third electrode

Parallel connexion is possible, but the controlled rectifiers must be matched to have similar forward voltage drops and similar triggering characteristics.

Triggering currents are in the order of 10 mA to 100 mA, while the duration of a pulse required to trigger the diode is as low as 5 to 10 μs. Once triggered, the diode will continue in its low-resistance state in the forward direction until the main current drops to a low value, of the order of 30 mA, when it will return to its high-impedance state in both directions. In the

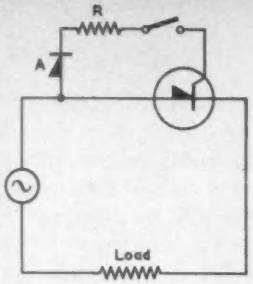


Fig. 15 Simple half-wave switch. As there is no mechanical wear, a controlled rectifier could replace a relay with advantage here

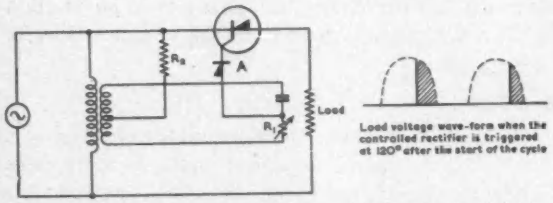


Fig. 16 Half-wave supply with phase-shifting circuit. A load current of many amps may be varied by means of a trigger current of a few milliamps

triggered state the forward voltage drop is in the order of 1 to $1\frac{1}{2}$ V.

A very simple circuit for a half-wave switch is shown in Fig. 15. The rectifier *A* is to prevent inverse current in the trigger circuit during the inverse half cycle. The resistance *R* limits the trigger current. When the controlled rectifier has fired, it will shunt the trigger circuit, and reduce the trigger current to negligible values.

Fig. 16 shows a phase-controlled, half-wave supply. By varying resistor R_1, the controlled rectifier may be triggered at any point from the start of the cycle up to virtually 180° later. This of course provides a variable, half-wave supply. The figure shows the wave-form of the voltage across the load when the controlled rectifier is fired 120° after the start of the cycle. R_2 in the circuit limits the trigger current while rectifier *A* prevents inverse currents in the trigger circuit.

Fig. 17 shows a phase-controlled full-wave supply.

As mentioned earlier in this article, the current required to trigger a controlled rectifier varies with junction temperature. Therefore, if precise control or timing is required, it is preferable to replace the *RC* phase-shifting circuit with one capable of giving a steep wave-front.

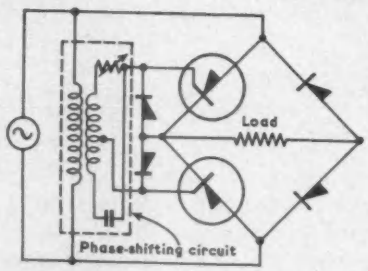


Fig. 17 Controlled full-wave supply

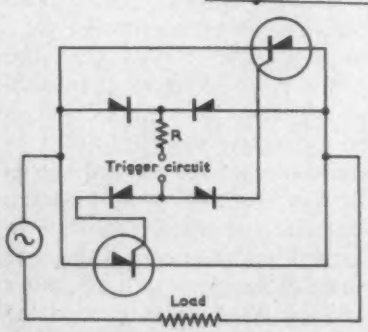


Fig. 18 A.C. control or switch. Not only can this circuit act as a simple a.c. switch, but the load current can be varied continuously

Fig. 18 shows a circuit for high speed a.c. switching. The controlled rectifiers replace the relays or contactors of a more conventional circuit. Advantages include higher speeds and absence of mechanical wear. By means of phase-shifting circuits or suitable signals from transistors, the effective voltage output can be controlled.

Fig. 19 shows a d.c.-to-a.c. converter circuit. This, obviously will have a wide application in converting battery supplies into a.c. supplies. The addition of a rectifier in the output makes the circuit into a d.c.-to-d.c.

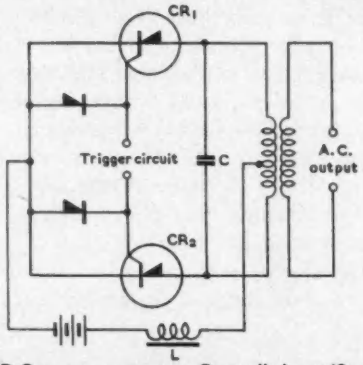


Fig. 19 D.C.-to-a.c. converter. Controlled rectifiers can be used to build a compact, rugged and efficient d.c.-to-a.c. converter

converter. The mode of operation is as follows: The trigger circuit alternately supplies a triggering pulse to CR_1 and CR_2, the two controlled rectifiers. Suppose that CR_1 is conducting and CR_2 is blocking, then the current will flow in the upper part of the transformer. The voltage developed across the primary and also the capacitor *C* will be twice the d.c. supply. When CR_2 is triggered, the voltage across CR_2 will fall to a very low value and the capacitor voltage will be impressed across the controlled rectifier CR_1 in the inverse direction, for a sufficient time to allow CR_1 to regain its blocking state.

CR_2 will conduct and capacitor *C* will be recharged, but this time with a reversed polarity. When CR_1 is triggered the capacitor will then extinguish CR_2. The inductance *L* is to prevent excessive current during switching. The output wave from this supply will be approximately square.

Conclusions

The controlled rectifier is a new semiconductor device of far-reaching importance. Not only will it replace the thyratron in a great many applications, but it will undoubtedly open up a number of new fields. Its efficiency and mechanical robustness will make it attractive for use in a wide range of applications and its fast response will make it very important where high-speed switching of high powers is required.

Acknowledgement

Acknowledgements are due to the A.E.I. (Rugby) Ltd. for permission to publish this article.

End

D.C. AMPLIFIERS FOR COMPUTERS

by **J. C. CLULEY**
Birmingham University

D.C. ELECTRONIC ANALOGUE COMPUTERS are now widely used for investigating a variety of engineering problems, and provide facilities for simulating systems and apparatus without the manufacture of expensive prototypes. Their high speed, accuracy and flexibility enable them to operate at the speed of, or faster than, the physical system being studied, and permit rapid evaluation of the effects of varying the system parameters.

The physical variables of the system are represented by varying electrical

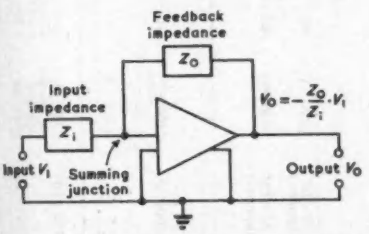


Fig. 1 General feedback computing circuit

voltages (generally within the range ± 100 V) which obey exactly the same equations. Since the independent variable on the computer is time, the most convenient application is the analysis of the dynamic behaviour of systems, but steady-state solutions may readily be obtained. The easiest problems involve only linear differential equations, but simple electronic circuits may be used to handle various non-linearities such as backlash, dead zones, and saturation. Other circuits are available which produce a signal representing the product of two voltages.

The size of an analogue computer depends upon the complexity of the problems handled; about six amplifiers will suffice for a third-order differential equation with one variable, whereas several hundred amplifiers may be required to investigate in detail the vibration of an aircraft in flight, or the temperature distribution within a nuclear reactor.

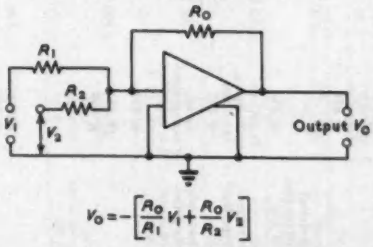
Analogue computers are generally organized as a number of linear computing units, which perform simple mathematical operations such as summation, multiplication by a constant, and integration, and a smaller number of non-linear units. These, together with generators to represent various input signals, and recording and indicating meters, are interconnected by flexible leads on a patch-panel or plug-board which resembles a manually-operated telephone-switchboard. The remainder of the equipment consists of power supplies, and control and switching facilities.

The linear computing unit

The linear computing-unit comprises a number of resistors and capacitors, and a high-gain d.c.-amplifier connected in the voltage negative-feedback circuit of Fig. 1. In this arrangement the accuracy of the computation depends almost entirely upon the accuracy of the impedances Z_i and Z_o, and very little upon the gain of the amplifier, if this is large. The nature of Z_i and Z_o depends upon the computing operation required, the two most important functions of summation and integration being shown in Figs. 2 and 3. Here only two inputs are shown for clarity, but more may be used if necessary.

In addition to high gain, the amplifier should have a high input impedance, so

Fig. 2 Summing circuit



as to avoid loading the impedances Z_i and Z_o; a low output impedance, so that the output voltage is almost independent of the load; and a sign reversal, so that a positive input-signal generates a negative output-signal. It is also necessary to control the rate at which the gain falls above the working frequency band, so as to avoid instability. The safety margin is usually indicated by the amount of capacitive loading which may be connected across input and output terminals before oscillation occurs. This is indicated in

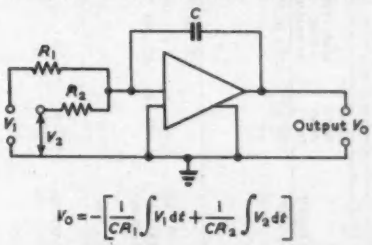


Fig. 3 Integrating circuit

the table, generally with 1-MΩ input and feedback resistors.

It is also necessary for the amplifier to be free from 'offset' or zero error, so that the output terminal is at earth potential when the input is also at earth potential. Under the above conditions the output and input voltages V_o and V_i of the general circuit of Fig. 1 obey the relation:

$$V_o = -\frac{Z_o}{Z_i} \cdot V_i \qquad \ldots (1)$$

Correction of zero-drift

At least three stages of voltage amplification are required to yield the overall gain of 20,000 or more necessary for precise computation, which should be maintained over a frequency ranging from 0 to 30–100 c/s. Unfortunately, although the zero of such an amplifier can be set accurately at the start of a computing run, it will drift slowly, owing

continued on p. 114

COMMERCIALLY AVAILABLE D.C. AMPLIFIERS

MAKE	TYPE	MAXIMUM OUTPUT Voltage	MAXIMUM OUTPUT Current	AMPLIFIER D.C. GAIN Main	AMPLIFIER D.C. GAIN Drift Correction	AMPLIFIER D.C. GAIN Overall	LONG-TERM ZERO DRIFT	EFFECTIVE GRID CURRENT	NOISE REF. INPUT	POWER REQUIREMENTS H.T.			Heaters	MAXIMUM CAPACITATIVE LOADING Input	MAXIMUM CAPACITATIVE LOADING Output	REMARKS
A.E.I. Ltd	DS 591 ★ 832	±100 V	20 mA	>30,000	>1000	4×10^6	<50 μV	$<5\times10^{-11}$A	<300 μV *p–p*	+300 V 2·5 mA (stab) 25mA(unstab)	−300 V 3·9 mA (stab) 25mA(unstab)		12·6 V 1·3 A c.t.			Two synchronous chopper-relays provide 100-c/s modulation in chopper amplifier. Bulk of h.t. supply need not be stabilized.
Airmec Ltd	261	±100 V	12·5 mA	30,000 at max. load	Not fitted			$<5\times10^{-10}$A		+300 V 34·5 mA max.	−300 V 6·8 mA max.	−170 V 51·5 mA max.	6·3 V 0·45 A 6·3 V 0·75 A (stab.)	33 *p*F	0·02 μF	No drift-correction.
	261+262 Drift correction amplifier ★ 833	±100 V	12·5 mA	30,000 at max. load	>600	18×10^6 (approx)	±100 μV	$<5\times10^{-10}$A		35·5 mA max.	6·8 mA max.	51·5 mA max.	6·3 V 0·7 A 6·3 V 0·75A	33 *p*F	0·02 μF	Overload indicator fitted to drift-correction amplifier.
Bruce Peebles Ltd	No. 1 Operational amplifier ★ 834	±100 V	5 mA	>3000	Not fitted		±10 mV max.		<5 mV *p–p*	+300 V 12·5 mA	−300 V 16·5 mA		6·3 V 1·5 A		0·002 μF with 100 kΩ feedback	Includes switched computing resistors and capacitors and optional diode limiting circuit. No drift-correction.
	No. 10 Drift-stabilized amplifier ★ 835	±100 V	5 mA or 10 mA	>10,000 (at 100 c/s)	3000 (approx)	$>30\times10^6$	<100 μV		<200 μV	+300 V 20 mA or 31 mA	−300 V 16 mA or 22 mA		6·3 V 2·1 A	250 *p*F	2 μF	
Brush Electrical Engineering Co. Ltd	A.C. 10 ★ 836	±100 V	5 mA	4000 at 100 c/s		20×10^6	70 μV per day	10^{-10}A	150 μV	+300 V 10 mA	−300 V 16 mA		6·3 V 1·8 A			
de Havilland Propellers Ltd	Transistor computing amplifier ★ 837	±10 V	30 mA			$>10^6$	<5 μV per °C	$<10^{-9}$A	2 mV	Maximum power consumption 500 mW per amplifier						Fully transistorized. Uses silicon diffused alloy transistor in place of mechanical chopper.
Electronic Associates Ltd	Dual transistorized d.c. amplifier type 6.112–1 ★ 838	±10 V	30 mA typical				50 μV (max.)	$1\cdot5\times10^{-9}$A (typical)	0·25 mV (typical)	Normally supplied from power unit of Pace TR–10 computer; total load on mains, including 20 amplifiers, less than 50 W						Fully transistorized, apart from mechanical chopper.
	16–6H ★ 839	±100 V	13 mA, 20 mA, or 33 mA	200,000 (average)	3000 (average)	600×10^6 (average)	75 μV in 24 hours	10^{-10}A (average)	5 mV peak	Normally supplied in cubicle complete with power supplies. Load approx. 3 kVA at 117 V, 60 c/s for 28 amplifiers						Boosted outputs of 20 mA or 33 mA available from each amplifier. Overload indicators and set-zero controls provided. Requires external chopper supply.
	6.002 ★ 840	±100 V	25 mA	30,000 (average)	4500 (average)	135×10^6 (average)		6×10^{-11}A (max.)	5 mV *p–p*	+300 V, +110 V, −300 V, −500 V			6·3 V			Four amplifiers are mounted in one package. Requires external chopper supply. Provision for overload indication. Set zero controls incorporated.
Elliott Bros. (London) Ltd	BEA ★ 841	±100 V	10 mA	25,000	400	10×10^6 (approx.)	±100 μV	10^{-11}A		+300 V 40 mA max.	−300 V 40 mA max.		6·3 V 1·75 A 6·3 V 0·3 A	80 *p*F with 2·2 MΩ resistor	0·05 μF (as integrator)	Uses plug-in hermetically sealed chopper relay.
(Manufactured by Panellit Ltd)	BAA Mk. II ★ 842	±100 V	10 mA or 20 mA (boosted)	25,000	1000	25×10^6 (approx)	±50 μV	10^{-11}A		+300 V 40 mA max.	−300 V 40 mA max.		6·3 V 2·2 A 6·3 V 0·3 A	80 *p*F with 2·2 MΩ feedback and input resistors	0·01 μF	Optional boosted output of 20 mA. Uses plug-in hermetically sealed chopper relay.
E.M.I. Electronics Ltd	Operational amplifier ACOA 1 / ACPA 1 ★ 843	±125 V	10 mA / 50 mA	15,000	600	7×10^6 (approx)	<100 μV	$<10^{-10}$A	<1 mV r.m.s.	+300 V 16±8 mA 50±40 mA	−300 V 16±2 mA 50±10 mA		6·3 V 1 A 6·3 V 0·9 A 6·3 V 1·75 A 6·3 V 1·35 A	100 *p*F (with 1 MΩ feedback resistor)	0·01 μF	ACPA 1 and ACOA 1 are identical apart from output stage. Switched amplifier ACSA 1 with same basic performance as ACOA 1 is available to constitute a multiplier, in conjunction with Modulator ACM 1
English Electric Co. Ltd	Lace amplifier unit *Operational amplifier* ★ 844	± 50 V	5 mA	65,000	1500	750×10^6	<100 μV per hour			+250 V 35 mA	− 250 V 35 mA	−500 V 1 mA	6·3 V, 1·5 A 6·3 V, 1·2 A			The amplifier unit contains a drift-corrected operational amplifier and a separate uncorrected buffer amplifier.
	Buffer amplifier	± 50 V	5 mA	65,000	Not fitted		<2 mV per hour									

English Electric Co. Ltd	Lace amplifier unit *Operational amplifier* *Buffer amplifier* ★ 844	± 50 V ± 50 V	5 mA 5 mA	65,000 65,000	1500 Not fitted	750×10^6	<100 μV per hour <2 mV per hour			+250 V 35 mA	− 250 V 35 mA	−500 V 1 mA	6·3 V, 1·5 A 6·3 V, 1·2 A			The amplifier unit contains a drift-corrected operational amplifier and a separate uncorrected buffer amplifier.
Ericsson Telephones Ltd	Dataflex Operational amplifier N810003E1 ★ 845	±6 V	12 mA	10,000	1000	10×10^6	<50 μV random <5 μV/°C	$<10^{-9}$A random $<10^{-10}$A/°C	<100 μV r.m.s.	+12 V 18–28 mA	−12 V 18–28 mA					Fully transistorized. Input impedance 6 kΩ in parallel with 30 pF. Requires 1 kc/s square wave for drift correction amplifier.
Feedback Ltd	AD 1B ★846	±50 V	2 mA	1-20, adjustable (A1) 1 or 150 (A2)	Not fitted		4 mV for 1 V h.t. variation or 0.1 V heater variation			+300 V 25 mA	−300 V 25 mA		6·3 V 1·5 A		100 pF	Two amplifiers mounted in 1 unit A1. Stabilized gain +1 to +20 adjustable A2. Switched gain −1 or −150. No drift correction.
General Precision Systems Ltd	CBD ★ 847	±100 V	10 mA	50,000	Not fitted		<12 mV	$<1{\cdot}2 \times 10^{-9}$A		+300V (stab) 2 mA +300V(unstab) 4–19 mA	−300 V (stab) 2 mA −300V(unstab) 9–14 mA		6·3 V 0·6 A 6·3 V 0·9 A	150 pF	>1 μF	CBO is identical with CBD, but has a drift-correction amplifier fitted. Overload indicators and zero setting facilities provided. Most of the h.t. current may be taken from unstabilized lines.
	CBDX ★ 848	+100 V	10 mA	50,000	750 (approx)	37×10^6	<100 μV	$<10^{-10}$A		+300V (stab) 2 mA +300V(unstab) 5–20 mA	−300V (stab) 2 mA −300V(unstab) 10–15 mA		6·3 V 0·6 A 6·3 V 1·24 A	150 pF	>1 μF	
	CBE ★ 849	±100 V	66 mA	50,000	Not fitted		<12 mV	$<1{\cdot}2 \times 10^{-9}$A		+300V (stab) 2 mA +300V(unstab) 1–72 mA	−300V (stab) 2 mA −300V(unstab) 6–73 mA	−500 V 40 μA	6·3 V 1·06 A 6·3 V 1·36 A	150 pF	>1 μF	CBE and CBEX are identical with CBD and CBDX respectively, apart from their high-power output stage, but require a −500 V bias line and more h.t. current.
	CBEX ★ 850	±100 V	66 mA	50,000	750 (approx)	37×10^6	<100 μV	$<10^{-10}$A		+300V (stab) 2 mA +300V(unstab) 2–73 mA	−300V (stab) 2 mA −300V(unstab) 7–74 mA	−500 V 40 μA	6·3 V 1·06 A 6·3 V 1·72 A	150 pF	>1 μF	
Miles Electronics Ltd	Drift-corrected d.c. amplifier ★ 851	±100 V	10 mA 20 mA or 35 mA			$>300 \times 10^6$	<100 μV	10^{-10}A	<5 mV	+300 V 30 mA 40 mA 55 mA	−300 V 30 mA (for 10 mA output) 40 mA (for 20 mA output) 55 mA (for 35 mA output)		6·3 V 3·2 A			Alternative output currents of 10, 20 or 35 mA may be selected by moving a shorting link. Zero-setting and overload indication provided.
Louis Newmark Ltd	Model 3000 ★ 852	±100 V	5 mA	10,000 min.	Not fitted		<4 mV per hour	$<10^{-9}$A	<1 mV r.m.s.	Power supplied by basic model 3000 computer						Not drift-corrected.
	Model 3101 dual amplifier ★ 853	±100 V	13 mA	50,000	1000	50×10^6	±100 μV per week	3×10^{-11}A (average)	<2 mV r.m.s.	+200 V 20 mA (for two amplifiers)	−200 V 25 mA	−416 V 0·5 mA	6·3 V3 A	1000 pF	1000 pF	Power requirements given are for zero signal. One chopper only required for two channels.
Newman Industries Ltd	7570 dual amplifier ★ 854	±60 V	2 mA	2000 (approx)	Not fitted					+250 V 10 mA (for two amplifiers)	+100 V 3 mA	−250 V 10 mA	6·3 V 1·5 A			Not drift-corrected. Two amplifiers mounted in one unit.
Saunders Roe	SR 400 ★ 855	±50 V	10 mA	>100,000	>1200	$>120 \times 10^6$	<50 μV	$<10^{-10}$A	<1 mV r.m.s.	+300 V 26 mA	−300 V 15 mA		6·3V 2 A		10,000 pF	Provision for overload indicator.
Short Bros. & Harland Ltd	Type C linear function unit ★856	±50 V	5 mA	10,000 (approx)	1000 (approx)	$>12 \times 10^6$	<50 μV	10^{-10}A (approx)		Normally supplied complete with power units in cubicle containing 18 amplifiers						Overload indicator fitted. Includes two switched resistor and one switched capacitor banks as computing impedances.
	High gain amplifier ★ 857	±100 V	10 mA	100,000	1000 (approx)	100×10^6 (approx)	<25 μV	10^{-11}A (approx)	<200 μV	+300 V 38 mA max	−300 V 38 mA max		230 V a.c. to transformer	2000 pF	10,000 pF	Overload indicator and set-zero facilities provided. Sealed chopper unit.
Solartron Electronic Group Ltd	AA 621·2 ★ 858	±100 V	5 mA (or 10 mA)	>30,000	1000 (approx)	$>30 \times 10^6$	<100 μV	$<10^{-10}$A	100 μV typical	+300 V 20 mA (31 mA)	−300 V 16 mA (22 mA)		6·3 V 2·1 A	250 pF	10,000 pF	Includes set zero facilities and overload indication. Max. output 5 or 10 mA selected by connexions on power socket.
	AA 621·2 plus cathode follower unit TA 828·2 ★ 859	±100 V	25 mA (or 50 mA)	>30,000	1000 (approx)	$>30 \times 10^6$	<100 μV	$<10^{-10}$A	100 μV typical	+300 V 100 mA (144 mA)	−300 V 80 mA (110 mA)		6·3 V 3 A	250 pF	10,000 pF	Switch selects half (25 mA) or full (50 mA) output from cathode follower. Set zero and overload facilities provided on amplifier.
Teledictor Ltd	G 2/18 ★ 860	Depends upon h.t. supply	56 mA at 250 V h.t. 104 mA at 350 V h.t.	1300–1400 mA/V	Not fitted		<5 mV in 24 hours			+250 V (stab) 40 mA	−250 V (stab) 40 mA	250–350 V (unstab) 80–120 mA	6·3 V 0·6 A 6·3 V 3·75 A			Power amplifier for feeding split field servomotors. Unstabilized supply for output valves can be varied to suit load requirements. Push-pull input stage.

★ For further information, circle this number on reply card facing page 178

to changes in valve and component characteristics. This drift will cause unacceptable errors in a lengthy solution, particularly if many integrators are used. It is therefore general practice to provide continuous zero-drift correction for all accurate computing work, by using an auxiliary drift-free amplifier as shown in Fig. 4. Any zero-drift which occurs will result in a signal at the summing junction, on account of the voltage feedback through Z_o and Z_i. This is amplified by the auxiliary amplifier and fed back into the input stage of the main amplifier as a drift-correction signal. By this means the zero-error may be reduced by a factor of 200–1000, the limit generally being the residual errors of the correction amplifier. This is usually an a.c. amplifier handling signals modulated

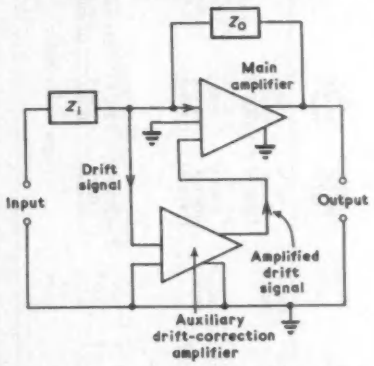


Fig. 4 Basic circuit of drift-corrected computing amplifier

by a polarized 'chopper' relay, which also demodulates the amplified signal. After smoothing, the signal is fed back to the input stage of the main amplifier with the polarity arranged to correct the zero-drift. The high degree of smoothing needed to eliminate ripple at the chopping frequency causes a time lag of several seconds in the amplifier response, but since zero-drift signals are much slower than this the amplifier performance is satisfactory.

This drift-correcting technique reduces the zero-drift from a figure of several millivolts per hour for an uncorrected amplifier, to a typical long-term value of 100μV referred to the input terminal.

A consequence of the arrangement of Fig. 4 is that both amplifiers are in cascade at very low frequencies, so that the d.c. gain of the complete unit is of the order of 10^7. This falls to that of the main amplifier alone, usually 10^4–10^5, at frequencies above about 0·2 c/s, at which the drift-correcting amplifier is inoperative.

Effect of grid current

All amplifiers inject a small current into the summing junction from the first valve in the main amplifier and the chopping circuit, generally classed as *effective grid current* in amplifier specifications. This produces errors, particularly a constant rate of change of output-voltage V_o in integrating circuits, given by the relation:

$$\frac{dV_o}{dt} = \frac{i_g}{C} \text{ V/sec} \qquad \ldots (2)$$

where i_g = effective grid current (A), and C=value of integrating capacitor (farads); consequently some manufacturers specify the drift rate for a given capacitor (usually 1 μF) instead of the value of i_g. This drift rate determines the maximum duration of a computing run with a prescribed error: e.g. a 1-V error (1% in a 100-V system) arises in 16$\frac{1}{2}$ min. using a 0·1-μF capacitor with the typical grid current of 10^{-10} A.

Use of transistors

On account of a number of difficulties, such as low input-impedance and low voltage-rating, the transistor compares unfavourably with the thermionic valve as the active element of a computing amplifier. It also suffers from the temperature dependence of some parameters, notably the collector leakage-current when the emitter is biased to cut-off, and the input base-to-emitter voltage when passing a given current. Nevertheless, its inherent advantages of small size, lightness, low power-consumption, reliability and robustness make it an otherwise very attractive choice, and the recent availability of silicon transistors, with leakage currents of 10^{-9} A (several thousand times below that of germanium transistors), has permitted the design of transistorized amplifiers of adequate performance as regards drift- and input-current. Also, high-voltage transistors are now available to permit output-voltage amplitudes of $\pm$ 30 V.

A further advantage of the transistor is that it can be used as a switch, to replace the chopper relay. Although the short-circuit resistance is larger, and the open-circuit resistance smaller than that of the relay, there is no mechanical limitation to the speed of operation, so that much faster chopper-amplifiers may be constructed, and no maintenance is required. This technique is used in two of the three transistorized amplifiers included in the table. At the present time the transistorized amplifier cannot compete with the thermionic-valve amplifier where the utmost accuracy or very long computing runs are required, but for most engineering applications, where input data suffer from some uncertainty, its performance is more than adequate. For special-purpose computing, where space, power, and weight are at a premium, as in many airborne applications, the transistorized computing-amplifier has clear advantages.

Form of construction

Most amplifiers are constructed on printed-circuit boards, with plug connexions for signal leads and power supplies, complete with auxiliary drift-correction amplifier. There are, however, variations from this. For example, Louis Newmark fit two amplifiers, sharing a common chopper-relay, on one circuit board, and Airmec supply the main amplifier and drift-correction amplifier on two different chassis. The main amplifier alone can then be used for the less onerous duties, such as sign reversal, or both units used together to constitute a drift-corrected operational amplifier. Also, since both polarities of a signal are frequently required, English Electric incorporate a separate amplifier in their computing-amplifier chassis as a sign-reversing or buffer amplifier. For a small computing-installation, Bruce Peebles incorporate some switched computing-impedances and an optional diode limiting-circuit in their simple operational amplifier. Several amplifiers have arrangements to increase the available output current by operating a switch or making external connexions. This 'boost' facility should be used only when necessary as it requires extra current from the h.t. lines. Where particularly heavy currents are required, of the order of 50 mA, it is more convenient to produce an alternative amplifier with a high-current output-stage (E.M.I. Electronics) or an additional high-current output-stage to use in conjunction with a standard amplifier (Solartron).

The provision of overload indicators, and facilities for setting the zero accurately (preferably controlled from the front panel), simplify the use and setting-up of computing networks.

Power supplies

All computing amplifiers require at least two electronically stabilized h.t. supplies, typically $\pm$ 300 V; a third supply at $-$ 170 V or $-$ 500 V is used in some cases, generally simplifying the design of the final amplifier stages. A.E.I. use only a few milliamperes from stabilized supplies, the bulk of the h.t. supply being unstabilized.

Heater supplies need not be stabilized, but zero-drift can be reduced if a constant-voltage transformer is used. As these require isolation, one or two separate heater-windings are required for each computing amplifier. Most manufacturers produce standard power-units to supply a number of amplifiers, together with housings into which amplifiers may be plugged, and power wiring.

The amplifiers included in the table range from simple amplifiers for inexpensive computers, to fully-drift-corrected very-high-gain units for large-scale high-precision computers.

DATA SHEET 21

Frequency response plots: the Nichols chart

Graphical techniques for control systems—7

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THE NICHOLS CHART IS A PLOT OF THE frequency response of a system, gain in dB being plotted as ordinate and phase as abscissa, with ω as a parameter. Fig. 1 illustrates a typical chart for a servo-system and compensating network. Conveniently the origin O is taken as 0 dB and $-180°$, so that OA′ gives the phase margin directly and OA the gain margin. The transparency, Fig. 2, gives contours of constant magnification and phase, and is used in conjunction with the frequency response locus to complete the Nichols chart.

Compounding of loci

This is illustrated with reference to Fig. 1. The locus $KG[j\omega]$ for the uncompensated system indicates too low a gain margin. The locus $A[j\omega]$ relates to a lag-lead compensating network to be used for series compensation. To compound the two loci it is necessary only to add gain or phase values for corresponding ω values, as the plot is logarithmic. This procedure is illustrated in Fig. 1 for a specific value ω_x. The phase value for the compensated system is given by OA′ + BC where BC = O′D numerically. At E the phase values for the compensating network change sign so that e.g. for ω_5 the phase angle is given by OG + O′F (lagging).

Gain adjustment

This merely requires a vertical translation of the phase axis upwards for a decrease and downwards for an increase.

Mesh of curvilinear squares

As ω is a parameter, a mesh of curvilinear squares can be constructed on the locus, using the procedure outlined in (*1*). A plot for a system with the open loop transfer function

$$G_0 = \frac{0{\cdot}75[1+0{\cdot}2s]}{s[1+0{\cdot}2s][1+0{\cdot}05s]}$$

is shown Fig. 1. The construction gives $\alpha \simeq \pm 0{\cdot}96$ and $\beta \simeq \pm 1{\cdot}6$, to show that two of the roots of the 5th order characteristic equation arising in the closed-loop transfer function are $s \simeq -0{\cdot}96 \pm j1{\cdot}6$. Substitution of these roots in Eq. 1 serves as an accuracy check: here the positive ω root gives $G_0/\phi = 0{\cdot}98\angle -182°$, a close approximation to the desired value of $1\angle -180°$. Using these roots the 5th order equation can be reduced to the product of a quadratic and a cubic, which is relatively easily factorized.

Contours of constant amplification and phase

These are analogous to the M and N circles pertaining to the Nyquist diagram (*2*) and can be plotted from these or from the following relations.

As a complex number

$$G_0/\phi_1 = (1+1/R[\exp -j\alpha])^{-1} = (1-\cos\alpha/R - j\sin\alpha/R)^{-1}$$

Expressing this in terms of the phase margin α gives

$$G_0/\phi_1 = (1-\cos\alpha/R + j\sin\alpha/R)^{-1} \quad (3)$$

and (*4*)

Defining $M = |G_0/\phi|$ and $N = /G_0/\phi$ gives $M = (1+1/R^2 - 2\cos\alpha/R)^{-1}$ and $N = \tan^{-1}[-\sin\alpha/(R-\cos\alpha)]$. These are the curves plotted on a dB and phase-margin basis in Fig. 2 and by superimposing these on the open loop locus the peak overshoot can be assessed by locating the point of tangency of the system locus with the corresponding M contour and the phase margin from the corresponding phase-contour. Since these contours are symmetrical about the gain axis the response locus can be reflected about this axis (Fig. 1), the transparency being reversed, with a corresponding reversal of phase values (*3*), (*4*).

References

1. Meadows, N. G.: '*Data Sheet 15, Graphical techniques for control systems—4*', *Control*, 1960.
2. Meadows, N. G.: '*Data Sheet 13, Graphical techniques for sampled systems—2*', *Control*, Sept. 1956.
3. James, Nichols and Phillips: '*Theory of Servomechanisms*' p. 179 et seq.
4. Chestnut and Mayer: '*Servomechanisms and Regulating System Design*' p. 318 et seq.

Fig. 1 (left) Compounding loci

Fig. 2 Transparency facing this page

3 (below) of curvi- squares

As well as the regular news-letter from our special correspondents in the United States, we have this month two reports from British visitors there

Look at America

This month: servo-valves—backlash—mechanical amplifier—gyroscopes—J.A.C.C. Conference—self-organization—synchros

Electrohydraulic servo-valves

Within the last few years, several newcomers have entered the highly competitive electrohydraulic servo-valve field with strikingly unique products. At the same time, of course, the older companies have been progressing rapidly in the improvement and expansion of their line of high-performance valves.

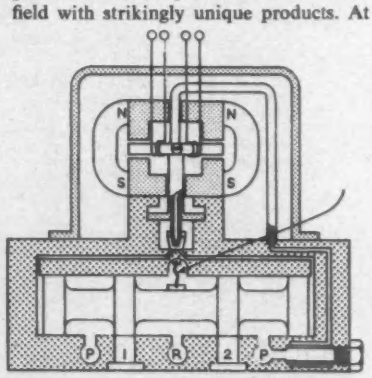


Fig. 1 Atchley valve—arrow indicates force feedback to jet pipe

Among the newcomers is Raymond D. Atchley, Inc., which offers a two-stage valve employing a jet-pipe preamplifier (*1*) (Fig. 1). The preamplifier, or first stage, acts as a frictionless high-gain force-feedback servo-mechanism to control the second stage. In the null position shown, a very small amount of fluid flows continuously from the pressure cavity *P*, through a flexible pipe connected to the armature of the torque motor, and out of the single jet. When a differential current is applied to the torque motor, the jet pipe moves toward one of the two receiver ducts, causing an unbalanced force on the piston. As the piston moves, a force-feedback spring connected to it transmits a counteracting force to the jet pipe. The piston comes to rest when the force exerted by the feedback spring balances the force produced by the torque motor, and the jet pipe is again symmetrically positioned. One of the most important features of the valve is its ability to pass 200-μ particles through both first and second stages.

Another newcomer, the Kearfott Company, Inc., offers a two-stage valve with a 'shear-seal' preamplifier as the first stage (*2*). Fig. 2 illustrates the operation of the valve. Fluid from the input port passes through a screen and then through fixed orifices to chambers at each end of the spool. Passages in the spool lead to two variable orifices at either side of the centre. Varying the current in either torque-motor winding displaces the armature, and thus the slide fork, resulting in a differential pressure which repositions the spool. A new equilibrium among pressures in the load ports, drain port, and the supply is then established. At null, the slide fork closes the variable orifices. The 'one-to-one follow-up' characteristic of the valve is said to result in an inherent dither without requiring a modification of the electronic amplifier.

Particularly striking among the new valves is the 'flow-control' valve developed by Dr S.-Y. Lee of the Massachusetts Institute of Technology in co-

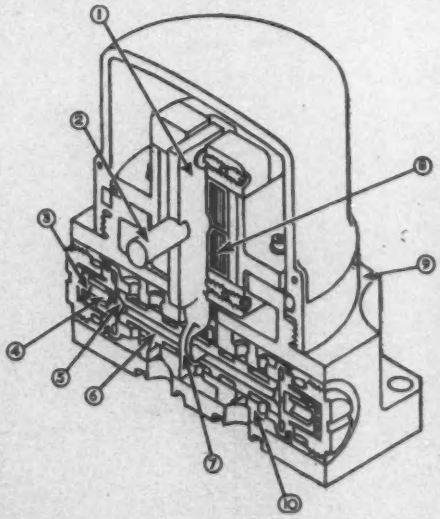
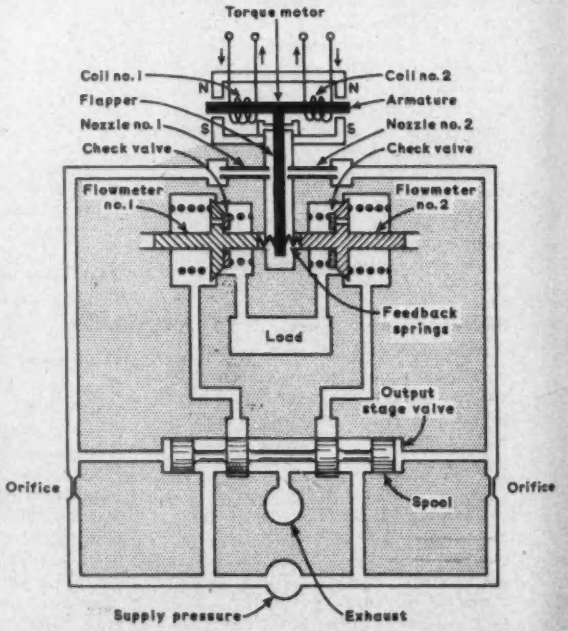


Fig. 2 (left) Kearfott valve. 1 Balanced-armature. 2 Torsion-rod pivot. 3 Filter screen. 4 Magnetic trap. 5 Fixed orifice. 6 Metering spool. 7 Shear seal covering variable orifices. 8 Torque motor. 9 Stabilized body and sleeve assembly. 10 One-piece sleeve

Fig. 3 (right) Servo-valve with flow feedback



operation with Pesco Products Division, Borg-Warner Corporation. In contrast to conventional servo-valves, which operate on the principle of controlling the position of a precision-made four-way or three-way valve, with the hope that the flow rate will follow accurately the input signal to the valve, the 'flow-control' valve represents an entirely novel approach to servo-valve design. This new device, which uniquely employs flow feedback, is said to eliminate the necessity for a high-precision valve, to give a greater life-expectancy for the valve, and to minimize the effects of load-pressure, exhaust-pressure, and supply-pressure variations. The operating principle of the valve is best understood by referring to Fig. 3. Five major components make up the valve: (a) A torque motor which produces a torque proportional to an electrical input, (b) a first-stage preamplifier (a flapper-nozzle valve configuration used in this particular case), (c) a second-stage valve (spool type) which regulates the flow to the load, (d) a pair of area-type flowmeters which senses the rate of flow to the load, and (e) a pair of feedback springs which feeds back the flow signal and completes the loop. The flowmeters used are simple, accurate, linear, and have a very fast response rate. Although the high performance of the flowmeters depends on a relatively large drop across the meter, this pressure-loss is only a few per cent of the supply pressure of a typical high-pressure system.

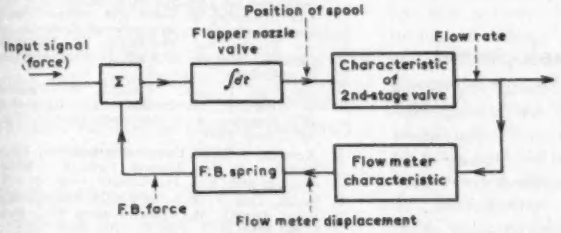


Fig. 4 Simplified block diagram of servo-valve with flow feedback

The operational diagram of Fig. 4 best explains the role of the flowmeter. Since the first-stage valve is an amplifier of very high gain, the steady-state output-flow-rate from the valve is almost entirely dependent on the performance of the feedback loop. Thus, if the output flow rate is to vary linearly and accurately with the input signal, the flowmeters and feedback springs must be linear and accurate.

An extensive analytical and experimental program conducted to evaluate the flow-control valve has been well documented in the recent literature. In a paper by Bahniuk and Lee, a description of the construction and no-load performance of the flow-control valve is given (*3*). In addition to its many advantages over conventional servo-valves, the flow-control valve is shown to have steady-state and dynamic-response characteristics that compare favourably with those of other available high-performance valves.

For several years, servo-valve manufacturers have known that the slope of the steady-state pressure-flow curves is a measure of the damping in a system employing the valve. One might then question whether the flow-control valve, with its typically flat pressure-flow curves, can have a stable operation in the absence of other forms of damping. In a paper presented at the recent Ifac Congress in Moscow, S.-Y. Lee analyses the dynamic performance of the flow feedback valve used in conjunction with a pure inertia load (*4*). The author shows that when the flow-control valve is used to control the speed of a pure inertia-type load, the damping due to the slope of the pressure-flow curve of the output stage of the valve (for a constant displacement input) still exists even when the slope of the pressure-flow curve of the complete valve (with constant input signal) is practically zero. Although this particular type of damping is somewhat less than that available with a typical position-feedback-type valve, the difference is small when the inertia load is small.

A very recent addition to the servo-valve field from one of the older companies, Moog Servocontrols, Inc., is a subminiature two-stage valve weighing only 5·12 ounces. The valve employs a flapper-nozzle preamplifier and a second-stage spool. Maximum flow capacity of the valve is 3 gal/min at 3000 lb/in².

Elimination of limit cycles resulting from backlash

A technique for dealing with control-system instabilities and limit cycles caused by backlash has been proposed recently (*5*). Using a describing-function representation of the backlash element, its characteristics can be plotted in a Nyquist diagram along with the frequency-dependent components of the system. A simple system might be represented by Fig. 5, which is modified to the form of Fig. 6 in order to separate the linear and non-linear portions of the loop. In either case, however, the condition for marginal stability is

$$1 + GN = 0 \text{ or } G = -1/N.$$

Hence the intersection in a Nyquist plot of the curves for $G(j\omega)$ and $-1/N$ determines the existence of a limit cycle (which may or may not be stable). The plot of $-1/N$ will depend on the amplitude of the sinusoidal input applied to the system, and the 'width' of the backlash or hysteresis, as defined in Fig. 7.

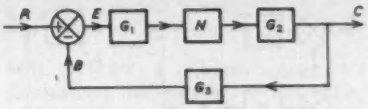


Fig. 5 Typical control loop containing a non-linear element (N)

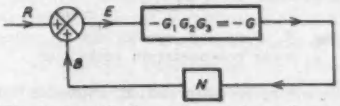


Fig. 6 Modified representation of control loop, separating linear and non-linear components. N is the describing-function representation of the non-linearity

Fig. 8 is a Nyquist diagram for the loop shown in Fig. 5, under the assumption that the linear elements in the system are of the form $G = G_1G_2G_3 = \frac{K(1+as)}{s(1+bs)(1+cs+ds^2)}$, and N is represented by the describing function for the characteristic of Fig. 8. The intersection of $G(j\omega)$ and $-1/N$ indicates limit-cycle behaviour at ω_c. The curve labelled $G_1(j\omega)$ represents the linear elements of the system as modified by the addition of a lead-lag network. For this situation it is seen that no intersection occurs at all, and the system will be well behaved at all frequencies. Hence linear compensation is one method for alleviating the effect of the non-linearity.

It is easily imagined that for other forms of $G(j\omega)$, ordinary linear compensation may not affect the Nyquist plot sufficiently to avoid an intersection with the $-1/N$ curve. For such situations, a second technique, called non-linear com-

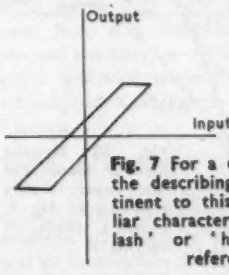


Fig. 7 For a development of the describing function pertinent to this only-too-familiar characteristic of 'backlash' or 'hysteresis', see reference 8

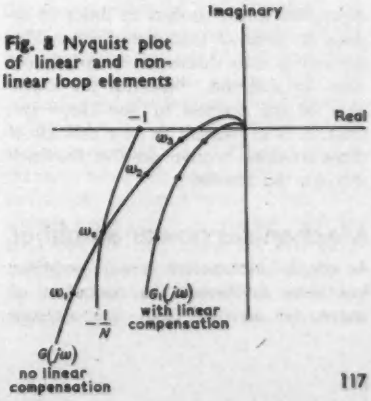


Fig. 8 Nyquist plot of linear and non-linear loop elements

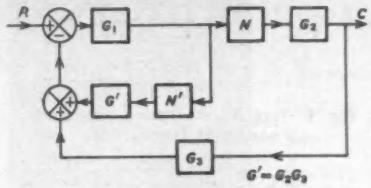


Fig. 9 Proposed application of non-linear compensation technique

pensation, is proposed as illustrated in Fig. 9. In this loop, a limit cycle will occur when $1 + NG_1G_2G_3 + N'G_1G' = 0$. If $G' = G_2G_3$, then this condition becomes $-1/[N + N'] = G_1G_2G_3$. Now notice that if $N' = 1 - N$, the effect of the non-linearity is completely nullified, and the ordinary Nyquist criterion for instability (open-loop gain = 1, open-loop phase = 180°) pertains.

It is of interest to study the case $N' = X(1 - N)$, where X is a number between 0 and 1, and hence represents the percentage of non-linear compensation. To illustrate system behaviour under this condition, the plot in Fig. 10 is made. In this case, $G(j\omega)$ remains constant, and the various curves of $1/[N + X(1 - N)]$ are plotted with X as a parameter. In a large sense, Fig. 8 is merely a special case of Fig. 10 for the condition $X = 0$. As before, an intersection indicating a limit cycle occurs for $X = 0$, but it is seen that stabilization can often be obtained by providing only a relatively small amount of non-linear compensation.

Schemes that employ 'modelled' components (such as N' in Fig. 9) in the feedback loop have also been proposed by other researchers. Reswick (6) suggests the use of a dynamic model of the

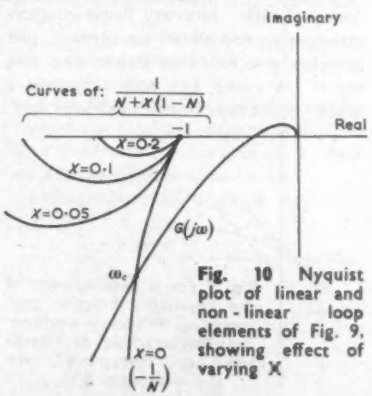


Fig. 10 Nyquist plot of linear and non-linear loop elements of Fig. 9, showing effect of varying X

controlled linear process in order to reduce the effect of load disturbances. This method is also discussed by Smith (7), who—in addition, illustrates the extension of the method to non-linear systems. It is of interest to note that all of these schemes involve positive feedback through the 'model'.

Mechanical power amplifier

A simple mechanical power amplifier has been developed, the operation of which is derived from the capstan principle as shown in Fig. 11 (9). If the coefficient of friction between cable and drum is f, and β is the total angle of cable wrap, then $T_1 = T_2 \exp f\beta$. The output speed and force can be varied by relatively low-power-level adjustments of the input force. Also, it is noted that if the input is moved to a new position, the output will follow exactly. In the product commercially available a pair

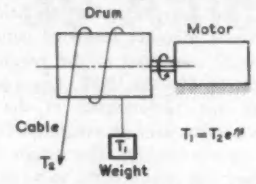


Fig. 11 Capstan principle of torque amplification

of counter-rotating drums driven by the same motor provide output motion in either direction. Torque amplification is 500:1, and power output is approximately ¼ h.p.

Gyroscope development

A new miniaturized floated gyroscope demonstrated recently by Minneapolis-Honeywell claims a 10-to-1 improvement in drift rate and a 30-to-1 reduction in noise (10). Two developments are responsible for the large improvement: a helium-gas bearing for the spin motor and ceramic parts for the gimbal structure and spin-motor stator. The gyroscope can be miniaturized, even with a gas bearing, because the spin motor has ceramic journals.

A gas-driven displacement gyroscope containing only four moving parts has recently been developed as a reference instrument for short-range missiles, drones, and target vehicles (11). According to designers, the gyroscope can outperform any other gas- or spring-driven example and offers a high degree of reliability at a fraction of the cost of conventional gyroscopes. At the start of a mission, its hot-gas drive, a liquid or solid propellant, accelerates the gyroscope to high speed and it automatically uncages. In flight, the gyroscope operates in a coast-down mode for the duration of the mission.

Joint Automatic Control Conference

The Joint Automatic Control Conference for 1960 will be held at the Massachusetts Institute of Technology, September 7–9; major responsibility for organization of this year's conference has been assumed by the American Society of Mechanical Engineers. The other participating societies are the Institute of Radio Engineers, American Institute of Electrical Engineers, Instrument Society of America, and American Institute of Chemical Engineers. Held each year, the J.A.C.C. is the only national inter-society control conference in the U.S. A selected list of the technical sessions includes *Optimal Switching, Chemical Process Dynamics, New Techniques in Control System Theory, Adaptive Control, Control Components, Non-linear Systems*, and a report on the Ifac Congress held in Moscow in June. A total of 61 papers is scheduled for presentation.

Your American Correspondents

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Massachusetts Institute of Technology

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Self-organization

For many people who know anything about cybernetics, the subject first became alive in 1948 when Norbert Wiener's book was published. In that book, the famous mathematician gave an account of the events of the previous five years that had led up to the recognition of a science of control and communication which would be interdisciplinary—especially as between the physical and the biological sciences. For had not nature devised control systems, culminating in the brain of man, of a subtlety that physics and engineering had never seriously conceived? And might it not prove possible to unravel some of the principles involved in rigorously scientific terms?

A year later, in 1949, the first of a series of five books appeared: the proceedings of the sixth annual (American) conference on cybernetics. The editor of the proceedings, and of those that followed, was the physicist Heinz von Foerster, a professor of the University of Illinois, and himself one of the pioneers.

All these early books were delightful, discursive, and somewhat dilettante for most of those involved were acknowledged authorities in their own personal fields, and probably none would have called himself a 'cybernetician', as a few do today.

Since then, cybernetics has grown auspiciously: as a corpus of knowledge, as a repository of theory, as a field of practical achievement. The science has many branches and many aspects, but at least one issue has emerged as of paramount importance. It is this: very large, very complex, very probabilistic systems defy the sort of identifications and analysis which alone would make them susceptible to orthodox control theory techniques; if they are organized, they themselves must supply the organizational power. The concept of the *self-organizing* system had crystallized out. Several workers had written about this explicitly. The notion had also gained ground and currency among cybernetic professionals at the first two international conferences (1956, 1958) on cybernetics which were sponsored by Belgium, and the important N.P.L. symposium (called *The Mechanization of Thought Processes*) held at Teddington in 1958.*

Illinois Symposium

This was the setting, and this the subject, for the meeting convened from June 7th to 11th this year at the University of Illinois, Urbana, Illinois. The sponsor was the U.S. Office of Naval Research, to which all present were heavily indebted; but it was von Foerster's symposium. There could have been no more appropriate convenor; nor could a more appropriate speaker have been found to open the proceedings (and subsequently to lend his august yet sympathetic presence to them) than Warren McCulloch. For he had been Chairman of the whole series of the original American conferences, and had been a pioneer of cybernetic work (it must be acknowledged) long before the name was officially selected.

The thirty members of the symposium were all protagonists in the field, or specialists in closely related areas, who between them must have represented most branches of human knowledge that bear on this problem. They were all specially invited: there was no general audience. Four of them came over from Britain. The whole group was installed by the university 25 miles away from Urbana itself in a mansion set in a park: as a cybernetic house party it was a huge success. Unfortunately, the formal proceedings alone were recorded, but these will be published (by Pergamon Press) as soon as may be.

*See *Control*, March 1960, pp. 107-9, for R. A. Brooker's review of the published proceedings.—EDITOR.

Something of the flavour of the symposium may be gained by considering first a whole session in the field of network theory. One of the formal ways of tackling a self-organizing system is to think of it as a network of neurons. After all, the brain is a composition of such nerve cells (10^{10} of them), and the way the brain organizes itself to produce its familiar aptitudes is a topic worthy of study. Many people have worked on the problem of defining an artificial neuron in terms of logic, and of defining the connexions between neurons (some inputs tending to excite and some to inhibit the receiving cell) in a similarly rigorous way. Perhaps the leading exponent of this approach is McCulloch himself, who chaired this session of four papers—all contributed by members of his own group at M.I.T.

Leo Verbeek spoke about neuronal nets designed to minimize error in the transmission of information. Techniques for this purpose are based (as in the brain) on highly redundant networks, and it is many years since von Neumann demonstrated mathematically a possible mechanism which would cope with the 'death' of component neurons. There is no doubt that the M.I.T. work has vastly improved the efficiency of this mechanism, and Verbeek set out to show, in addition, how their nets would grapple with 'fits' as well as 'deaths'. But what of the merely *unreliable* component, the bane of the control engineer? Manuel Blum went on to describe infallible nets built entirely of unreliable neurons. There is now proof that information can still be transmitted up to an arbitrarily high degree of accuracy.

Now to construct a self-organizing system of neuronal nets, it is necessary to set up a homeostatic system of the kind rigorously described by Ross Ashby in his *Design for a Brain*. Jack Cowan dealt with this phase of the business, and explained his theory of its logic. Most of the extant work in network theory (particularly of the relatively elementary kind used in computer technology) uses a Boolean logic of two valves (0, 1). The M.I.T. work suggests (and McCulloch himself strongly asserts) that the full self-organizing system theory can only be achieved in terms of a many-valued logic such as Cowan discussed. Finally, Lars Lofgren talked about this very difficult problem: given uninterrupted and accurate computation with unreliable neurons, and with networks which incorporate both deaths and fits, what happens when so much has gone wrong that repair is essential? His answer, naturally, is that the system must be self-repairing; and he described a logic for this behaviour *which would not cause a stoppage*.

This symposium was international, and although these four men all presently work at M.I.T. it is worth noting their nationalities, respectively: a Dutchman, a Venezuelan, a Scot, and a Swede. Ross Ashby himself is, of course, British; he is surely the leading figure in theoretical systematic cybernetics (although he is an experimenter too). Thus his unique spot on the program, speaking on the principles of self-organizing systems, was inevitable. All present clearly regarded his survey, which cannot be repeated in this note, as inevitably masterly too. That is his reputation.

Pattern recognition

Another important session dealt with the self-organizing approach to the problem of pattern recognition—a subject which has become somewhat set of recent years in a distinctly different mould. (For there is nothing very self-organizing about linear scansion coupled with a diode logic based on Boolean functions.) This session, under the guidance of John Bowman, a Dean of Northwestern University and another of the early pioneers, was notable for two papers. First, J. R. Platt spoke with powerful illumination on the perception of pattern by mosaic receptors, such as the retina of the eye itself. How does such a jumble of unequal cells manage to detect a straight line, for example? Platt had the convincing answer, in a mechanism very unlike that normally invoked for an artificially rectilinear grid system. He was followed by Al Novikoff, speaking about statistical invariants of geometrical figures under translations and rotations. This was an exercise in integral geometry, accounting for pattern recognition by the random superimposition of arbitrary areas on arbitrary grids (remember Buffon's needle, the one-dimensional parent of this approach, which calculates the value of π ?). Rarely can such a *tour-de-force* have been seen and heard in such a learned assembly; if a fraction of Novikoff's brilliance transmits itself to the written record, this will be a paper to treasure.

Theory and experiment

It is pleasing to report that the other speaker who completely captured the audience intellectually and emotionally was an Englishman, Gordon Pask, under the chairmanship of von Foerster. He gave a long and intricate paper on the game-theoretic analysis of self-organizing systems, but ranged widely from the intricacies of the necessary mathematics to the habits of the slime mould—which organizes itself by chemical messages, and changes its whole organization in the course of its reproductive cycle. This address gained Pask an ovation, well deserved by the inventor of the first genuinely cybernetic machine to be marketed as a commercial proposition (the keyboard teaching machine, by Solartron).

Your present correspondent had the honour to be chairman of the session in which John Bowman delivered one of those child*like* yet far from child*ish* accounts of a seminal experiment with (who knows ?) far-reaching consequences. He had applied magnetic fields to a vast two-dimensional array of tiny toy magnetic compasses—of which he had, he said, 'bought a pint on the off-chance'. His paper, happily entitled *Bit Transmission Through Linear Arrays of Freely Rotatable Dipoles*, reflected profoundly on the self-organizing properties of such a system, commented ironically on the impossibility of *computing* these effects on the largest of machines, compared casually the patterns produced with those of the nervous system, and announced sensationally that a polymer constructed to imitate this arrangement (with amino-acids attached in place of the dipoles) ought to have staggering properties as a dielectric. George Zopf declared that he had already produced such a substance for other cybernetic purposes. Other key papers in this session were by Saul Amarel on automatic theory formation in logic; H. D. Crane on his 'neuristors', which offer a new method of exemplifying neuronal networks in practical hardware; C. A. Rosen, who delivered a most polished résumé of his approach to a distributive memory; and Peter Green, talking eruditely about the flow of information in self-organizing systems.

There is clearly no space here to give much more detail, although everything was of interest. One recalls the session chaired by that eminent economist, F. A. Hayek; and the superb paper investigating self-organizing systems by scrupulous investigation of small social groups with allotted tasks, which Anatol Rapoport (another early pioneer) delivered with his customary fluency and ease. The third Briton to be mentioned is R. L. Beurle, who spoke about his viable neurons—a long-standing contribution to network theory. There was a good deal of talk about solid-state devices, mixed in with so distinguished a lecture as that by R. W. Sperry on aspects of design in the living brain. Frank Rosenblatt gave the latest news of his Perceptron machine; and the eminent Ludwig von Bertalanffy interposed wise comments on much of the proceedings.

The only industrial application

The fourth of the Britons, namely the writer, contributed the only directly industrial application to be put forward, in his paper on the cybernetic factory—the more general portions of which paper were published in *Control* last June (p. 95). It is perhaps relevant to say, however, that the full paper as presented included a detailed set-theoretic formulation of a brain artefact conceived as a management aid, and also a chart of a year's 'encephalograph' readings of an actual company whose 'brain' had been simulated by this technique. The paper was rewarded by a very lengthy discussion.

The purpose of this brief review is to attest to the continued good health of active cybernetics, to attempt to convey some of the excitement that prevailed in Illinois among many excellent and distinguished international colleagues, and to give some impression of the scope of the interdisciplinary activity that goes to make up our subject. And (if the Editor will forgive this) it is also to make the hint as clear as possible that the printed proceedings ought to be worth having.

The United Steel Co's STAFFORD BEER

Synchros in the U.S.A.

The recent symposium on *Synchro Design and Testing* held in Washington, under the auspices of the U.S. Bureau of Naval Weapons, gave an interesting insight into current thinking on synchros in America. The symposium, which was organized to allow a formal exchange of views between manufacturers, users and the standardizing authorities, was the first of its kind to be held anywhere in the world, and an invitation was extended for a small party of British representatives to attend and present papers. Since there are now more than fifty firms engaged in synchro manufacture in the U.S.A., the response to the symposium was so great that the organization was almost overwhelmed, and eventually some 250 delegates attended the formal sessions.

This very large response was responsible for a delay in producing the preprints of papers, and they were not available until the morning of the first session. It was probably because of this that the discussion on papers was disappointing, considering the fact that all the leading authorities on synchros were present, and much of the useful interchange of ideas took place in extra-mural discussions.

Trend of design

The trend of design in the U.S.A. follows the now conventional pattern of smaller size, higher accuracy and higher temperature. The size-8 synchro (0·75 in. diameter) is now an established item available from a number of sources, although the requirements of the latest specification (MIL-S-20708) have not been fully achieved. Details of some proposed size-5 machines were given in a paper by Carlstein of Norden-Ketay; but, since the CT, CDX and CX versions were all quoted as having nearly equal impedances, a system resulting from the use of these synchros would not be very satisfactory and they are obviously very provisional.

Higher accuracies are being obtained in the larger units and study figures indicate that consistent accuracies of two minutes are possible in size-23 machines. In resolvers, however, much higher accuracies are possible, as was discovered later. An interesting machine described by Bendix consists effectively of a two-speed synchro system in a single size-18 case. This is achieved by having both two-pole and 22-pole windings on the stator, with two conventional windings on the rotor. With these machines, and suitable circuitry, an accuracy of thirty seconds can be obtained using normal production tolerances.

High-temperature operation is receiving a good deal of attention, particularly with regard to insulating materials and mouldings. It would appear, however, that the major barrier to progress above about 180°C lies in finding suitable bearings and lubricants. Dry, superfinished, ball bearings have been used up to 250°C for slow rotation and limited life, but this can only be regarded as a temporary expedient.

Several papers were presented on testing, particularly on the more controversial aspects of the new MIL-S-20708 specification, and on standardization. In this section the official British contributions were presented by C. G. A. Woodford of the Admiralty and L. G. Atkinson of the Royal Aircraft Establishment.

The symposium was undoubtedly a success and should mark the beginning of a series of regular gatherings for the exchange of ideas and information.

Synchros in production

Following the meetings the author spent a considerable time with the Kearfott Division of General Precision Inc. studying their production and design facilities; in particular their latest plant at Asheville, North Carolina. The company decided some years ago to site their new factory in an area where labour and land were more readily available than in their home state of New Jersey. After careful study, North Carolina was selected although it was appreciated that the personnel available would initially be unused to factory work.

This bold experiment has paid off, however, and the plant now turns out over fourteen thousand synchros a month, mostly size-11, although, despite the best efforts of the standardization authorities, each customer seems to require some slight modification to the standard machine. This has become so widespread that Kearfott have found it essential to be able to produce any required variant of a type in ninety days and the monthly output of 14,000 may include as many as 300 different varieties

of synchro. In order to cope with this diversity, the tooling must be flexible and simple and the widespread use of automatic equipment, with frequent resetting, is uneconomic. Manual work is therefore widely used, except in the production of basic piece parts, and the jobs have been broken down into simple operations suitable for semi-skilled labour.

With such a fluid production program, close engineering control is necessary and this is provided by experienced engineers on the shop floor whose job is to follow the batches at every stage of production to see that the correct operations are carried out. For production and quality control, a comprehensive I.B.M. installation is used. This department is fed with cards marked by the inspectors on each stage of testing and from these the day's production is analysed. This analysis lists the acceptances and rejections by type at each stage and compares them with the previous record. It is thus possible to compare the operation day by day and take action to eliminate a fall in quality. Without these controls it is difficult to see how such a complex production program could be progressed smoothly. In all, the plant is an excellent object lesson in the production of high-precision components, with labour completely new to the work, and of the application of business machines to product control. The company still produces a large number of synchros at its New Jersey plant, especially highly accurate instruments for guidance systems. The trend in this field is away from the 'three-phase' synchro of standard design and towards the synchro-resolver. Because of the basic symmetry of this machine and the electrical isolation of its phases, high accuracies are more easily obtained than in the case of the synchro. A size-25 'pancake' resolver having an accuracy of 1½ minutes is in production, while a special resolver of the same diameter, but longer, having errors not exceeding thirty seconds, is available in small quantities.

Same problems but bigger market

The general impression obtained was that the American manufacturers have as many problems, and frequently the same problems, as their British counterparts. They have the advantage of larger markets and wider fields from which to draw their materials, but the design problems remain the same. Much of the more advanced work is carried out on Government contract, either directly or indirectly, and many of the elaborate and expensive pieces of test equipment have U.S. Government inventory plates on them. British designers, although less experienced, can probably match the Americans in inventiveness, but in facilities and equipment they are sadly hampered because of the relatively small home market for their products.

R. B. Pullin & Co. Ltd C. B. FLINDT

LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.S. British Computer Society. Brit.I.R.E. British Institution of Radio Engineers. I.E.E. Institution of Electrical Engineers. I.Mech.E. Institution of Mechanical Engineers. R.Ae.S. Royal Aeronautical Society. S.I.T. Society of Instrument Technology.

MONDAY 5—SATURDAY 10 SEPTEMBER
2nd International Conference on Operational Research. Aix-en-Provence, France. Organized by: The International Federation of Operational Research Societies, 11 Park Lane, London, W.1.

MONDAY 5—SUNDAY 11 SEPTEMBER
S.B.A.C. Flying Display and Exhibition, Farnborough.

WEDNESDAY 7—FRIDAY 9 SEPTEMBER
Joint Automatic Control Conference, Massachusetts Institute of Technology, U.S.A.

MONDAY 12—FRIDAY 16 SEPTEMBER
A week's Residential Course on *Measurement for Automatic Control*. University of Nottingham.

MONDAY 12—FRIDAY 23 SEPTEMBER
The fifth Reactor School course on *The Control and Instrumentation of Reactors*. Durley Hall, Bournemouth. Applications: Reactor School, Harwell, Didcot, Berks.

MONDAY 12—FRIDAY 23 SEPTEMBER
3rd Congress of the International Association of Cybernetics, Belgium. Enquiries: The Secretariat, 13 rue Basse-Marcelle, Namur, Belgium.

TUESDAY 13—THURSDAY 15 SEPTEMBER
5th International Instruments and Measurements Conference and Exhibition, Stockholm. Details: AB Anders Beckman, Smalandsgatan 2, Stockholm.

WEDNESDAY 14—FRIDAY 16 SEPTEMBER
Congress of the Association Francaise de Calcul. Registration: The Secretary, Association Francaise de Calcul, Institut d'Astrophysique, 99 bis, Boulevard Arago, Paris 14.

SATURDAY 17 SEPTEMBER
Fourth National Students and Graduates Convention. *Computers in Industry*. University of Birmingham. Details: M. Honore, 126 Langdon Road, Knowle, Warwicks.

WEDNESDAY 21—FRIDAY 23 SEPTEMBER
1960 National Power Conference, Bellevue-Stratford Hotel, Philadelphia, Penn, U.S.A. Enquiries: K. J. Falck, Philadelphia Elec. Co., 1000 Chestnut Street, Philadelphia.

WEDNESDAY 21 SEPTEMBER—SATURDAY 1 OCT
Factory Equipment Exhibition, Belle Vue, Manchester. Industrial and Trade Fairs. Ltd., Russell St, Drury Lane, London, W.C.2.

MONDAY 26—FRIDAY 30 SEPTEMBER
I.S.A. Instrument-Automation Conference and Exhibition. Coliseum, New York.

TUESDAY 27 SEPTEMBER
Gas sampling for automatic combustion control, by R. Hardy; *Smoke density measurement*, by G. H. Laycock. S.I.T.

TUESDAY 27—WEDNESDAY 28 SEPTEMBER
Symposium on *Automatic Control*. I.Mech.E.

TUESDAY 27—THURSDAY 29 SEPTEMBER
Conference on *Ergonomics in Industry*. Details: Miss H. M. Clay, D.S.I.R., 14–18 Cornwall Terrace, Regent's Park, London, N.W.1.

TUESDAY 27—FRIDAY 30 SEPTEMBER
A Symposium on *Flow measurement in closed conduit*. (Invitation only.) Details: National Engineering Laboratory, East Kilbride.

WEDNESDAY 28—FRIDAY 30 SEPTEMBER
Electronics and Instruments Exhibition & Convention, Farmery Hall, Hull. Tickets: W. Birtwistle, 78 Shaw Rd, Rochdale, Lancs.

FRIDAY 7—SATURDAY 8 OCTOBER
Aviation Electronics and its Industrial Applications. Bristol College of Science and Technology. Registration: Hon. Secretary, South Western Section, Brit.I.R.E., c/o The School of Management Studies, Unity Street, Bristol, 1.

TUESDAY 11 OCTOBER
A brief survey of *The Principles of Automatic Control* by G. Heywood. 7.00 p.m. Borough Polytechnic. Details: G. L. H. Bird, Borough Polytechnic, London, S.E.1.

TUESDAY 18 OCTOBER
A repeat of *The Principles of Automatic Control* by G. Heywood. (See Tuesday 11 Oct.)

TUESDAY 18—FRIDAY 21 OCTOBER
First Effluent and Water Treatment Exhibition and Convention. Seymour Hall. Thunderbird Enterprises Ltd., 140 Cromwell Road, London, S.W.17.

WEDNESDAY 19—WEDNESDAY 26 OCTOBER
Interkama International Congress and Exhibition for Instrumentation and Automation, Düsseldorf.

TUESDAY 25 OCTOBER
Pneumatic Instruments in Process Control by N. Robertson. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

TUESDAY 1 NOVEMBER
Automatic Control of Operations and Processes in the Ford Thames Foundry by K. H. Lee. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

TUESDAY 8 NOVEMBER
Electronics in Process Control by C. G. Seeds and W. Barber. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

TUESDAY 15 NOVEMBER
Automatic Control of Machine Tools by J. W. Smith. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

MONDAY 21—WEDNESDAY 23 NOVEMBER
International seminar on *Analogue computation applied to the study of chemical processes*, Brussels. Details: R. Vichnevetsky, 43 rue de la Science, Bruxelles 4, Belgium.

TUESDAY 22 NOVEMBER
Automatic Control of Boiler House Plant by P. J. Wheeler. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

TUESDAY 22—THURSDAY 24 NOVEMBER
Conference on electronic telephone exchanges. I.E.E.

TUESDAY 29 NOVEMBER
Automatic Control in the Steel Industry by M. H. Butterfield. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

LOOKING FURTHER AHEAD

MONDAY 9—WEDNESDAY 11 JANUARY 1961
7th National Symposium on Reliability and Quality Control. Bellevue-Stafford Hotel, Philadelphia, Pa., U.S.A.

WEDNESDAY 15—FRIDAY 17 FEBRUARY 1961
1961 International Solid-state Circuits Conference. University of Pennsylvania and the Sheraton Hotel, Philadelphia, Pa., U.S.A.

MONDAY 27—FRIDAY 31 MARCH 1961
3rd National Symposium on Temperature. Its Measurement and Control in Science and Industry. Columbus, Ohio.

TUESDAY 9—WEDNESDAY 17 MAY 1961.
International Exhibition of Measurement, Control, Regulation and Automation (Mesucora) and 58th Exhibition of French Physical Society, C.N.I.T., Paris.

MONDAY 26 JUNE—SATURDAY 1 JULY 1961
International Measurements Conference, (Imeko), Budapest. Details: Prof. J. F. Coales, Cambridge University, Trumpington St., Cambridge, or Imeko Secretariat, Budapest 5, P.O.B. 3.

WEDNESDAY 4—THURSDAY 12 OCTOBER 1961
Second Electronic Computer Exhibition and Symposium. Details: D. C. Scoones, Peat, Marwick, Mitchell & Co., 94–98 Petty France, London, S.W.1.

WEDNESDAY 8—FRIDAY 10 NOVEMBER 1961
Conference on *Non-destructive testing in electrical engineering*. I.E.E.

A monthly review—under basic headings—of the latest control engineering developments for all industries; specially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to INTEGRATION

Electrical system for recorders

A new integrating system introduced by Honeywell Controls, to work in conjunction with strip-chart recorders, has a number of interesting features. It is basically electrical, and uses a conventional slotted disk and light source to produce a digital output. A subsidiary output from the counter is fed back to the recorder, to make marks on the chart time-base representing equal increments of the integrated quantity. This arrangement allows the integral over any particular period to be found without taking counter readings—a facility which is particularly useful in gas chromatography.

The main components of the system are shown in Fig. 1.1. A transmitting slide-wire, *R*, is supplied from a standardized d.c. voltage source. The moving contact on this slide-wire is mechanically connected to the recording pen, so that the voltage output is always proportional to the measured value of the variable. This output is applied to the armature of motor *M*.

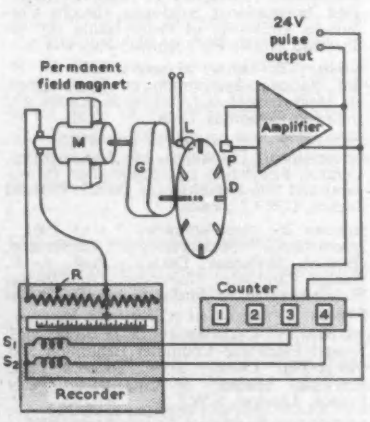


Fig. 1.1 Schematic diagram of the integrating system

By certain departures from normal d.c. motor design practice, the motor *M* is made to give a speed-response which is accurately proportional to the supply-voltage, provided that the applied load is light and constant. (The most important departures from standard practice are the use of a permanent magnet for the field, and an armature with an 'air-core', i.e. using no iron. Other mechanical refinements, such as jewel bearings and gold-wire brushes, are incorporated to eliminate varying friction loads.)

The motor armature-shaft drives the slotted disk *D* through the gear-box *G*. The disk interrupts a light-beam directed at the photo-transistor *P*, producing an electrical pulse-output which is amplified and used to drive a counter. An alternative pulse-output is available for feeding to data-reduction equipment or digital computers. Two advantages result from using this form of output from the integrating motor: firstly, a light and nearly constant load is imposed on the motor, so that its accuracy is unimpaired; secondly, changes in counting rate can readily be effected by changing the disk.

Two further pulse outputs, initiated by the 'tens' and 'units' sections of the counter, energize the solenoids S_1 and S_2 in the recorder. These solenoids operate pens which show on the chart, on opposite sides of a base line, the occurrence of each change in the appropriate counter digit. Thus the areas under any part of the record, however erratic, can easily be found.

. . . to DISPLACEMENT

Differential-transformer transducers with d.c. transmission

J. E. FIELDEN, M.Sc., M.I.E.E., *and* R. G. LLOYD, B.Sc., *Fielden Electronics*

In basic design, the differential transformer is well known. It comprises a core of magnetic material moving in a coil consisting of a primary winding and two secondaries. When the core is in the central position relative to the two secondaries, the output from these windings is equal, so that if they are connected in phase opposition the differential output is zero. Any movement of the core produces a differential output from the two secondaries and, by care in design, the relationship between voltage output and core position can be made linear.

This then, is an extremely useful component, since it is a true position transmitter needing no springs to convert position to force; it is robust, will operate without adjustment or attention, and can be constructed so that it will work at relatively high

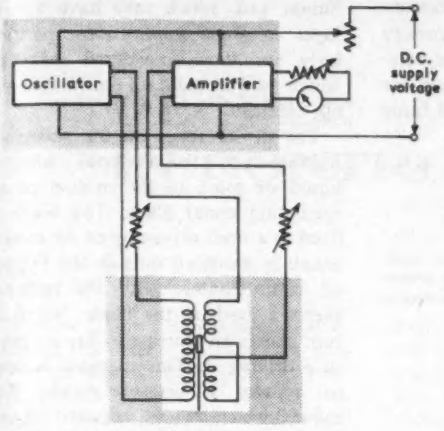


Fig. 2.1 The complete transmitting equipment. The supply and output signal are both d.c., a.c. for the differential transformer being locally produced by the oscillator. A rectifier in the amplifier unit re-converts the amplified signal to d.c.

temperatures, the only limitation being the materials used for the former and insulation of the coil.

In the past, differential transformers have been incorporated in industrial transmitters but owing to the manner in which they have been used they have not yet gained wide acceptance. In most cases a mains frequency supply has been used for the transformer itself, so that the inductive reactance of the coils is comparable with their resistance. Under these circumstances, the differential transformer is a very inefficient device. The slightest variation in manufacturing detail, or change in the lengths of transmission leads, produces variations in phase of the output voltage. This makes it extremely difficult to pre-calibrate transducers and displays so that they are interchangeable, and nearly all installations call for individual calibration or adjustment on site.

With a.c. transmission, experience has shown that pick-up on the wiring can introduce serious zero- and scale-errors, which vary with the current loading on adjacent power wiring, and are not necessarily apparent on commissioning. These and other drawbacks have proved so serious that a.c. transmission is now generally considered unacceptable for process control, but as long as suitable equipment is available to provide d.c. transmission, this is no reason why the differential transformer should be discarded.

A transmitter using a differential transformer can have advantages over the force-balance type which is becoming popular for d.c. transmission, since it is less affected by vibration or shock. This is particularly so since true force-balance transmitters are limited to those applications in which the force to be measured is comparatively small, and of the same order as the force which can be developed by a coil and magnet. Many so called 'force-balance' transducers use springs to convert movement to force, which introduces a further source of inaccuracy and again makes the transmitter susceptible to vibrations.

A system recently introduced by Fielden Electronics eliminates these troubles by using a differential transformer having a locally generated high-frequency supply for the transformer itself, and d.c. transmission to the receiving equipment.

The following design criteria were laid down for this system: (1) it should transmit d.c. in simple unscreened leads; (2) the d.c. output should be available up to 15 mA, to make the transmitters compatible with other electronic systems; (3) the relationship of output current to core position should be linear; and unaffected by variations in supply voltage or line resistance; (4) The transformer should operate satisfactorily with cores of small diameter, enabling thick-walled tubing to be used for high-pressure applications. (Note: the differential transformer core can be inside the pressure enclosure, with the windings outside); (5) the equipment should satisfy established standards of ruggedness in design and the electronic circuit should be housed separately from the sensing head, so that temperature limitations on the electronic components do not restrict the applications of the head; (6) the equipment should operate at low voltage and low current, so that it can be used in areas where an explosion hazard exists.

The equipment developed to satisfy these requirements consists essentially of an oscillator, a differential transformer and an amplifier (Fig. 2.1). The oscillator and the amplifier are housed in one unit and are energized from the same 12-volt d.c. supply, whilst the differential transformer is housed separately with the appropriate primary measuring element.

The oscillator

In order that the equipment should be unaffected by variations in the primary resistance of the differential transformer with temperature, the oscillator is designed to deliver a *constant current* a.c. output at a frequency of approximately 1200 c/s. This frequency was chosen to give the best compromise between high mutual inductive reactance and low capacitive shunting.

The basic circuit is shown in Fig. 2.2. The transistor amplifier A_1, has an output circuit incorporating a transformer primary winding which resonates at approximately 1200 c/s. One of two secondary windings on this transformer supplies current to the output terminals and to a resistor R in series with the output. The resultant voltage across R, which is proportional to current, is rectified and compared as a direct voltage with a futher direct voltage derived from a constant volt-

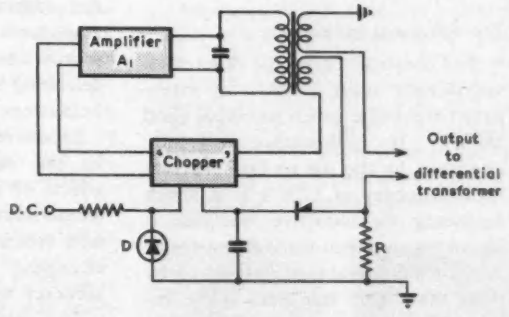


Fig. 2.2 The oscillator. By feeding back the voltage developed across the resistance R, the output current to the differential transformer is kept constant

age source, the Zener diode *D*. The difference in these two voltages is applied to a transistor 'chopper' operated at resonant frequency, and the resultant a.c. output from this chopper is fed back to the input of the amplifier. The operation of the circuit is as follows:

The circuit will oscillate when the feedback is positive and the gain of the complete loop is greater than unity. Thus the oscillator attains an amplitude such that the d.c. voltage derived from *R* is sensibly equal to the standard voltage derived from *D*. Any further increase in the voltage derived from *R* beyond this point will reverse the phase of the feedback and reduce the amplitude of oscillation. In practice, the gain of the amplifier is such that the d.c. voltage developed by the oscillation differs from the standard voltage by less than 0·1%. The primary current of the differential transformer is therefore maintained constant, independent of supply voltage, lead resistance and transformer winding resistance.

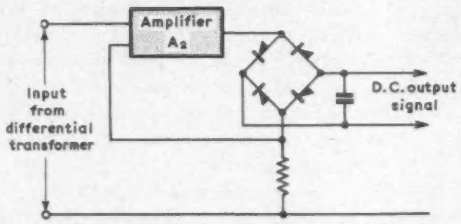


Fig. 2.3 The amplifier unit. The output is rectified before transmission to the receiving instrument

The differential transformer

The construction of the differential transformer itself follows an established technique which produces good linearity. Its performance is greatly improved by the use of the relatively high frequency of 1200 c/s, at which frequency the inductive reactance is high compared with the coil resistance.

A further advantage introduced by using this higher frequency is the improved performance when operating with a small-diameter core. When this core is of the order of $\frac{1}{16}$ in. diameter, the sensitivity is still ample for the following amplifier, and the high degree of linearity is maintained. This allows thick-walled tubing to be used to isolate the core in a high-pressure area. Since the transformer windings are outside the enclosure and are at atmospheric pressure, no moving spindles or electrical connexions are brought out through pressure seals. Advantages are gained by this feature in the design of differential-pressure cells, and it also allows a core relatively light in weight to be used for application where only a limited force is available.

The amplifier unit

This operates off the same 12-volt d.c. source as the oscillator, accepting an a.c. input and producing a d.c. output. A schematic arrangement is shown in Fig. 2.3. It consists of a transistor amplifier A_2 with high forward gain and bridge-rectified output, enabling the output d.c. to be fed back as a proportional a.c. voltage, this relationship remaining constant. The high feedback ratio gives the amplifier an input impedance of approximately 150,000 ohms. As the differential transformer secondary resistance is of the order of only 150 ohms, a change of 100% in coil resistance would produce an error of only some 0·1%. Obviously normal changes due to temperature variation will be only a fraction of this figure.

As the a.c. feedback is related to the d.c. output at any output level, the amplifier represents a constant current source and is therefore capable of delivering a current independent of the output circuit resistance.

Extensive tests have been carried out on this equipment to ascertain the effects of changes in supply voltage, temperature and line resistance. These tests indicate that for the applications envisaged for this transmitter, the accuracy will be within $\pm 0{\cdot}25\%$.

The equipment described above is the subject of a number of British and foreign patents.

. . . to LEVEL

Mechanical level-detector

Not all materials are ideally suited to the electrical and optical methods of 'on/off' level indication which are currently popular in bulk-handling schemes. A basically mechanical device has recently been introduced by Henry Simon Ltd, which may have advantages in some applications, particularly for those powdered materials which tend to build up on the measuring element.

The device relies on the resistance produced by the material, whether liquid or solid, to the motion of an oscillating metal blade. The blade is fixed to a shaft driven by an air motor, which is mounted outside the hopper or tank. Contact with the material exerts a load on the blade, which in turn causes an increase in the air pressure driving it. This increase is used to actuate a pressure-switch. The switch, which can be adjusted to suit different materials, produces an electrical signal to give the required indicating or controlling function.

. . . to TRANSMISSION

Information by light beam

An ingenious, if somewhat restricted, method of transmitting verbal instructions without a cable connexion has been introduced by G.E.C., under the name of 'Optiphone'. Relying on a voice-frequency-modulated light beam, the system is limited to applications, such as overhead travelling cranes, where the receiver is either stationary or moving in a straight path.

The transmitter consists of a carbon microphone, push-pull amplifier and transmitting lamp, the lamp giving a parallel light beam which is directed at the receiver. The amplified signal from the microphone is fed to the lamp, which thus gives a modulated light output. A 6-V battery applies a bias to the lamp to give a suitable mean operating intensity.

At the receiver, the modulated-light beam is focused by a lens on to a photo-transistor. The output from the transistor, which is proportional to the intensity of light falling on it, is fed to an amplifier. Speech is finally reproduced by a loudspeaker which is transformer-coupled to the amplifier output.

An advantage of this method of communication is that it does not suffer from radio interference, and a Post Office licence is not required.

We regret an error in last month's Ideas Applied, *in the caption to the diagram of the 'Contora' variable-speed gear, at the top of p. 123. The last part of the caption should read 'the outer ring F of the free-wheel', as in the text, not 'the outer ring E of the free-wheel'.*—EDITOR.

PEOPLE IN CONTROL

by Staffman

I visited Elliott's Borehamwood establishment the other day and ran into **T. M. B. Rybak,** just appointed Panellit's General Manager. He tells me that we are about to hear more of Optimat, their process control computer. On the same occasion—a pre-Farnborough review (see also pages 84 to 87)—Cmdr **H. Pasley-Tyler** (Assistant Managing Director) spoke of the reasons why firms such as his bother themselves with the difficult and barely-profitable operations entailed in designing aeronautical control systems. It appears that they accept this because the aircraft industry's requirements are of a high standard, and they are able to keep the whole Elliott-Automation group abreast of advanced development by moving engineers from the aircraft field into the more down-to-earth group-member firms. Incidentally, I hear from **A. M. Allen,** Sales Manager of Panellit, that **O. Smyth** has been appointed their Systems Sales Engineer to specialize in analogue computers. Smyth was with de Havilland Propellers concerned with control systems and computers for guided weapons.

Charles A. Escoffery and his 1912 Baker electric brougham were in the limelight last month—a most accomplished performance. Dr Escoffery, whose parents were English, is now Technical Assistant to the President of International Rectifier—an American company linked with Metal Industries through their joint control of International Rectifier (G.B.). He has been over here explaining solar cells to his rather less dynamic kinsmen. In spite of Dr Escoffery's successful demonstration of his brougham, I feel there is little future for sunshine-powered motor-cars in this country.

A keen amateur photographer, **Keith Lockyer,** has been appointed General Manager of Donvin Instruments & Dumar Optics, the Pullin group's instrument, camera and tape-recorder repair firms. Lockyer has worked with Solartron, Plessey and Philips, and was appointed General Manager of Victoria Instruments when Pullin took them over.

I hear from Taylor Controls that they have formed a Regional Office in Manchester to handle the north of England and Scotland, a Regional Office in Birmingham to cover the Midlands, south west England and south Wales, and opened a new Branch Office in Middlesbrough to cater for north-east England and Scotland. Several new appointments are involved. **F. W. Phillips** becomes Technical Sales Manager; **R. G. Robertson,** Field Sales Manager; **J. B. McCormack,** Northern Area Regional Manager; **E. S. Jerams,** Midland Area Regional Manager; **R. G. Barton,** London and Home Counties Area Manager; **G. A. J. Hall,** north-east England and Scottish Area Manager; **G. A. Mead,** Technical Sales Representative, south-west England and south Wales, and **N. P. Newton,** Technical Sales Representative (Chemical) London and Home Counties.

Firth Cleveland Instruments are also setting their house in order. They have merged their industrial and aircraft sales divisions into a single Home Sales Department under **S. F. Smith**—now Homes Sales Manager of the company. Previously Smith was Home Sales Manager of the Industrial Instruments Division. **H. F. Bagley,** who held a similar position on the aircraft instruments side, is appointed Deputy Sales Manager. Bagley is still responsible for sales of aircraft instruments but, as Smith's deputy, will also be concerned with industrial instruments.

Fairbanks-Morse and Co. (a subsidiary of the Fairbanks Whitney Corp. of New York), have recently established an Electronics Division. One of its main activities will be to market E.M.I. Electronics' products in the U.S., and I discussed this with **John Tompkins,** the new Division's General Manager, who is assistant to **David Karr,** the Fairbanks Whitney president. Tompkins is enthusiastic about the prospects of exchange of ideas, and quotes **Gordon R. Anderson,** Executive Director of Fairbanks-Morse, as saying that 'E.M.I. products are highly competitive and technically second to none . . . there is a great market for them in the States.'

AUTHORS IN CONTROL

J. J. Foody (*Controlling v.t.o.l. aircraft at transition speeds,* page 88) graduated from Queen's University, Belfast in 1948 and joined Short Brothers & Harland. He became Short's Chief Mathematician in 1954 and Head of the Analytical Department in 1957. He was Chairman of the Belfast Branch of the British Computer Society for the year 1959–60.

J. H. Westcott (co-author with H. H. Rosenbrock and J. C. West—below—of *Control engineering in the U.S.S.R.,* page 92). See page 121, August 1960.

H. H. Rosenbrock graduated from University College, London, and served in the R.A.F. during the war and until 1946. He was with the G.E.C. Research Laboratories from 1947–48, and teaching during 1948–49. He then moved to the Electrical Research Association, remaining there until 1951 when he joined John Brown & Co. In 1954 he transferred to Constructors John Brown and has been C.J.B.'s Research Manager since 1957. Dr Rosenbrock specializes in the theory of automatic control and its application to the control of processes.

J. C. West took his electrical engineering degree at Manchester University, and served in the Royal Navy as an Electrical Officer during the last war. His interest in automatic control stems from work with the Navy's Anti-submarine Warfare Branch. He returned to Manchester University on the staff in 1946, and built up a research laboratory in servo-mechanisms, specializing in non-linear problems of control. Since January 1958 he has been Head of the Electrical Engineering Department at Queen's University, Belfast. In 1952, he published the *Textbook of servomechanisms* (E.U.P.), which is now used as a basic text in many universities and colleges. His new book, *Analytical techniques for non-linear control systems,* devoted exclusively to non-linear problems, will be published this summer. Professor West believes that academic life should be integrated with industry and he is a consultant to A.E.I., British

ANDREW

WEST

Nylon Spinners and Short Brothers & Harland.

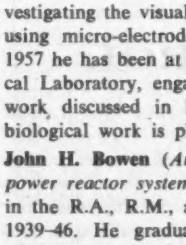
Alexander M. Andrew (*Learning in control systems*, page 99) attended Glasgow University from 1942 to 1944, and 1947 to 1949, graduating in mathematics and natural philosophy. The intervening three years were divided between a Government research establishment and an industrial organization, developing electronic devices, for speech scrambling in

BOWEN

SHEARER

the one case and for production testing in the other. From 1950 to 1957 he belonged to the Departments of Physiology and Psychological Medicine of Glasgow University, engaging in physiological research as well as the development of electronic apparatus. Eighteen months of this period was spent (on leave of absence from Glasgow) with Warren McCulloch's group at the Massachusetts Institute of Technology investigating the visual system of the frog using micro-electrode techniques. Since 1957 he has been at the National Physical Laboratory, engaged mainly on the work discussed in his article. Further biological work is planned.

John H. Bowen (*Automatic control of power reactor systems*, page 104) served in the R.A., R.M., and R.E.M.E., from 1939–46. He graduated from Swansea with an honours degree in electrical engineering in 1949. He then joined the



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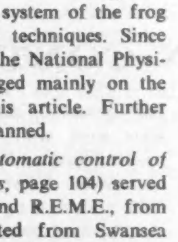


SCHER

Atomic Energy project of the Ministry of Supply, and spent several years measuring the control characteristics of reactors at Harwell. Later he became a member of the design team working on Calder Hall, initially at Harwell on the technical outline, and later at Risley on details of the control and instrumentation. He is now Chief Technical Officer of the Safeguards Division of the United Kingdom Atomic Energy Authority and, as such, is concerned with specifying safety standards for reactors.

A. J. Sadler (co-author with P. A. Turner — below — of *The silicon controlled rectifier*, page 108). See page 121, August 1960.

P. A. Turner. See page 121, August 1960.

J. C. Cluley (*D.C. electronic amplifiers for computers*, page 111) spent four years in the electricity supply industry prior to seven years' service with the Royal Corps of Signals. After demobilization he was in the development laboratory of Birmingham Sound Reproducers for six months, before reading for an honours degree in electrical engineering at Birmingham University. This was followed by a year's post graduate research on valve noise for the degree of M.Sc. He then became a research engineer at the Nelson Research Laboratories of the English Electric Co., where he was mainly engaged on the development of electrostatic storage tubes. He spent three years as a lecturer at the County Technical College, Stafford, before returning to the University of Birmingham as a lecturer in Electrical Engineering. Cluley has specialized in the field of electronic computing and supervised research on a nuclear reactor simulator.

N. G. Meadows (*The Nichols chart*, page 115). See page 173, May 1960.

J. Lowen Shearer (special American correspondent with Robert S. Scher and Karl N. Reid—below; *Look at America*, page 116), Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, is leader of the Control Engineering Division of the Mechanical Engineering Department. He graduated a B.S. in Mechanical Engineering from Illinois Institute of Technology, Chicago, in 1944 on completion of the co-operation program which included over four years' experience as an apprentice engineer in the Hydraulic Division of Sundstrand Machine Tool Co., Rockford, Illinois. During the latter part of his time with Sundstrand, Professor Shearer was closely associated with early work on the constant speed alternator drive which was subsequently used on B-47 and B-52 aircraft. After two years' service in the United States Naval Reserve he commenced graduate studies at M.I.T., in the Autumn of 1947. Subsequently, a combination of graduate study and teaching and research in the design and controls area led to the S.M. (1950), M.E. (1952), and Sc.D. (1954) degrees. He is currently a member of the Dynamic Systems Committee and Chairman of the Education Committee of the Instruments and Regulations Division of the American Society of Mechanical Engineers. He is a member of the American Society of Engineering Education, Tau Beta Pi, Pi Tau Sigma and Sigma Xi.

Robert S. Scher received his Bachelor of Science degree in 1956 from Massachusetts Institute of Technology, Master of Science degree in 1958, and Mechanical Engineer degree in 1960. His Master's thesis was entitled *Theoretical and laboratory performance of a pressurized journal bearing with positional feedback control*. He is now engaged on a program of research and study leading to the degree of Doctor of Science. Scher is research assistant in the Dynamic Analysis and Control Laboratory, Department of Mechanical Engineering, M.I.T. His paper *Development of a gas-operated, reaction jet servomotor* was presented at the I.Mech.E's Symposium on Recent Mechanical Engineering Developments in Automatic Control. He is an instructor at the Lowell Institute School, Cambridge, Mass., and a member of Pi Tau Sigma, Tau Beta Pi, and Sigma Xi.

Karl N. Reid received his B.S. degree in mechanical engineering from Oklahoma State University in 1956 and his M.S. degree in 1958. He entered Massachusetts Institute of Technology in September 1959 as a candidate for the mechanical engineer degree. Reid worked one year as a full-time research assistant and one year as full-time teaching assistant in the Dynamic Analysis and Control Laboratory of M.I.T. His teaching activities as assistant instructor include courses on basic and advanced automatic control, and hydraulic and pneumatic controls. His research activities have included basic work on hydraulic and pneumatic control valves. Reid is a member of Pi Tau Sigma, Sigma Tau, Omicron Delta Kappa and Sigma Xi.

Stafford Beer (*Self-organization*, page 118). See page 121, June 1960.

Shearer, Scher and Reid are sending a regular news-letter to *Control*.

C. B. Flindt (*Synchros in the U.S.A.*, page 120) received his engineering training at Cambridge University (Clare College), graduating in 1943, and was subsequently commissioned in the Electrical Engineering Branch of the Royal Air Force. On demobilization he joined the Bristol Aeroplane Co., working on instrumentation for gas turbines. Further aircraft instrument experience followed with Kelvin & Hughes and Teddington Controls. Following a digression into industrial instrumentation with the North Western Gas Board, he joined the Research Department of Short Brothers & Harland at Belfast. There he worked on automatic control of aircraft, particularly the S.C.1 v.t.o.l. machine, and eventually headed the Electro-mechanical Section. Flindt is now Deputy Chief Development Engineer of R. B. Pullin & Co.

NEWS ROUND-UP

from the world of control

MOTOR CARS

Bluebird's brake controls

Further details have been received of the various equipments of control interest in Donald Campbell's Bluebird land-speed-record contender, in which he is expected to make his 400-plus mile/h attempt on September 12, or shortly after. It has, of course, the Kelvin-Hughes collimated instrument display—a combined accelerometer and speedometer with indication on the car's windscreen—discussed in these columns last month. It is also fitted with Didas, Armstrong Whitworth Aircraft's 'dynamic instrumentation data automobile system.' The latter is a telemetry equipment which displays temperatures, pressures and positions, at eighteen points on the engine, gear-box and suspension, for observation by engineers in a Land Rover which may be fifteen miles away. Exactor main engine and air-brake remote controls are used, the latter controlling the hydraulic rams which operate the flaps forming the aerodynamic brakes.

As braking a four-ton vehicle travelling at 400 mile/h is no mean feat, the wheel brakes are supplemented by the aerodynamic brakes mentioned above, and Electro-Hydraulics are responsible for both systems. The braking systems are powered by compressed air in bottles, the wheel system being pneumatic throughout, in order to reduce the risk of fire. It is duplicated so that if either system fails, the other takes over automatically and supplies all four brakes without calling for action on the part of the driver. Air pressure is metered to the brakes by a duplex control valve operated by the driver's pedal, while a separate hand control applies the full operating pressure to the brakes for parking.

In the aerodynamic brake system, hydraulic fluid couples the two jacks to ensure the maintenance of aerodynamic symmetry. A servo-mechanism connecting the control lever, the selector valve and one of the brakes enables the position of the brakes to be determined.

Wheel brakes

Each of the four wheel-brakes is fitted with an unbalanced shuttle valve and is actuated by either of the duplicate supply systems. One system supplies both the normal large-area sides of the front-brake shuttle valves and the emergency small-area sides of the rear-brake shuttle valves. The second system supplies the other sides of these valves. If one system fails, the shuttle valves of the two brakes which it supplies move over automatically and the other system will actuate all four brakes.

Each system comprises an air bottle and one half of a duplex brake-control valve operated by the driver's pedal. Solenoid valves interposed between the air bottles and control valve remain closed until the initial movement of the brake pedal closes a micro switch; this eliminates leakage from the circuit when the brakes are not in use. To guard against electrical failure, the solenoid valve in one system may be by-passed with a manually-operated selector valve.

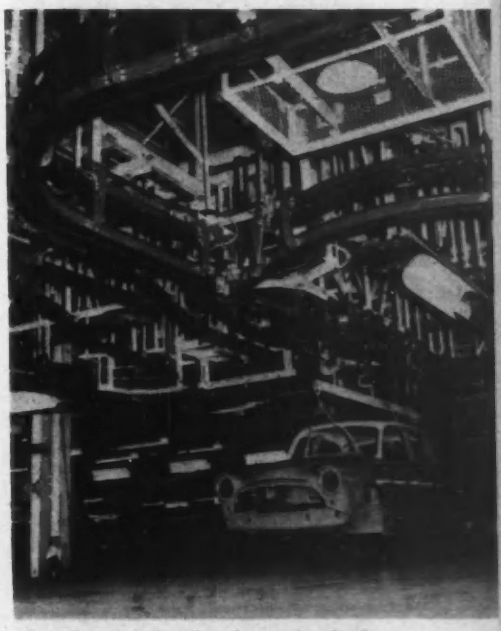
Aerodynamic brakes

The two air brakes are actuated by two interconnected hydraulic jacks. A twin-plunger three-position selector valve directs fluid from the supply accumulator to the jacks and thence to an unpressurized reservoir accumulator. To extend the air brakes, the selector is moved to connect the full-area side of the larger jack to the supply, and the annular side of the smaller jack to the reservoir; fluid displaced from the annular side of the larger jack flows to the full-area side of the smaller jack, which is of equivalent area, so that the movement of the two jacks must always be equal. Reversal of the selector reverses the connexions so that both jacks retract together; in the neutral position, all connexions are blanked.

The cockpit control lever operates a master cylinder connected hydraulically to an actuating jack which drives a linkage connecting the selector and one of the brakes. Control-lever movement is thus transferred to the selector and this supplies fluid to the jacks until the movement of the brakes, as transferred through the linkage, cancels the original displacement of the selector.

Simca's paint shop

The new paint shop of the Simca motor car plant at Poissy, France, incorporates an involved scheme of mechanical handling, two production lines operating, for the greater part of the process, in parallel, yet at widely differing speeds.



Simca's new paint shop has an involved conveying scheme by Geo. W. King

Geo. W. King Ltd. provided the conveying equipment, their design being for an automatic system which calls up bodies from the floor below, passes them through the various pro-

cess and inspection stages, delivers them to the trim line and, at the same time, supplies advance information to lines concerned with later processes.

An overhead conveyor system is used. The loaded trolleys are not fixed to the moving chain, but are propelled by pusher dogs fitted to the links. This allows transfer from one line to another, storage in live-line or dead-line, etc. It also enables the incorporation of drop sections in the system for the transfer of bodies from floor to overhead conveyors. A load trolley moves into the drop-section conveyor rail, where it is locked. The section is then raised or lowered and the trolley moved forward when coupled with the next conveyor.

Eighty bodies an hour

Bodies fabricated on two floor conveyors are elevated to an overhead conveyor by drop sections, and brought into the Paint Shop at a system-speed of 80 bodies an hour. A choice of two finishes is provided, so the conveyor system operates as two separate lines and at differing speeds. Before passing on to the feeder conveyor, therefore, limit switches are preset to distribute the flow of bodies to the two lines in the required sequence. A three-to-one ratio would mean a maximum of 60 on one line, and a minimum of 20 on the slower line. Leading bodies rest in indexers at the beginning of each line before being called for initial washing and sanding down. They are held at a further indexer until there are vacancies along the line, and are then automatically called into the bonderizing cabinet.

Next, the bodies are collected along a single conveyor. An automatic transfer unit, comprising rotating load-wheel with transfer arms, pushes the trolley along the single conveyor passing through the next stage while the second conveyor, from which load trolleys are transferred, is passed back along the outside of the bonderizer.

Control of this transfer unit is necessarily complex because of the differing speeds of the feeding conveyors. Both lines have indexers into which the bodies are gathered, and the transfer unit operates from the more fully loaded line.

A single conveyor then carries the bodies through a fine spray process, which simplifies surface-defect inspection, and on for any re-touching. The conveyor is then turned back for down-shop travel, at the same time returning to two lines at a ratio of three to one.

A complex system

After a bituminous dip and drainage, the bodies are primed and enter the first drying oven, where each line is divided evenly into two. As one body passes along a branch line, it operates a switch tongue to send the succeeding body down the second branch line.

After priming, bodies on the two sets of duplicated conveyor lines are knitted together into one single line. An automatic transfer unit receives bodies from the four lines and issues them to a floor conveyor, via a drop section, in the required sequence according to the body finish. Two different finishes and, in consequence, differing conveyor speeds, as well as two-tone colouring and any extra coats required, necessitate a complex conveyor system. Four sets of conveyors feed bodies to four paint-spraying units, two handling sixty bodies an hour, and two handling twenty. Transfer units break up the single line to distribute the bodies between two conveyors for passage through the drying ovens. At the end of the drying line, eight conveyors leave four ovens; these are directed into two lines, with the four conveyors converging on each through wheel-transfer units, and pass along to drop sections where they are taken below for trimming and assembly.

Automatic operation

The conveyor system with its associated indexers, wheel corners, drop sections, and automatic transfer units is controlled by relay-type equipment by Donovan Electrical Co., speed control being by Heenan & Froude variable-speed couplings. The conveyors are in six groups each controlled from a separate switchboard in the control room. Drop sections have separate local control panels.

The various transfer units have corresponding functional control panels, and the plant operator in the control room is able to set up the controls for the desired method of operation and to start and stop the plant at will. To his right and left are push-buttons for individual or group starting, selector switches for 'run' and 'inch' control, night storage and so on, together with the speed controls. A mimic diagram carries indicating lamps for all conveyors and transfer units, and banks of lamps indicate any abnormal operation.

Vehicle control

In a paper recently presented at the Road Research Laboratory, L. E. Flory of R.C.A. described an automatic traffic-control system being developed by his company. He made it quite clear that he thought some such system must eventually come into general use, and that it should perform two basic functions: communication between road and vehicle; and communication between one vehicle and a following vehicle.

The problem of road-to-vehicle communication for directional control is relatively simple. This can be achieved by having an induction cable, carrying a.c., embedded in the road, and simple detecting equipment in the vehicle which may provide signals either to the driver or for limited automatic control.

The equipment developed by R.C.A. for vehicle-to-vehicle communication was designed with the problems of the change-over period in mind—i.e., it was acknowledged that it would be impossible to equip all vehicles and all roads simultaneously, or even for a relatively short period only. Essentially the system comprises a sequence of wire loops embedded in the road surface, a series of detectors at the side of the road connected to these loops, and receiving equipment in the vehicles. The passage of a vehicle over the loops (irrespective of whether or not it is fitted with any special equipment) alters their inductance, and this change is used to produce a series of voltage signals in the road-side detectors. These signals, which decrease in strength with increasing distance behind the vehicle causing them, would operate transmitters. Receiving equipment in the following vehicle would pick up the signals, and extract information giving the distance ahead and speed of the initiating vehicle.

Flory admitted that there is as yet no agreement about how far automatic control of the vehicle—rather than merely the provision of extra information for the driver—is desirable. The equipment he described, which has reached an advanced stage of development and has undergone practical trials, could be used for either of these functions.

EDUCATION

U.S.A.F.'s teaching machines

Fourteen American Air Force students on an electronics course are being taught by individual teaching machines —Western Design's Auto Tutors—in an experiment being carried out by the United States Air Force. The test group covers a standard fifteen-week course, while a control group is taught the same course by conventional classroom methods.

The Auto Tutor is unusual in that, while requiring the student to show understanding at each step of the course, it lets him advance as slowly or as rapidly as he is able, while auto-

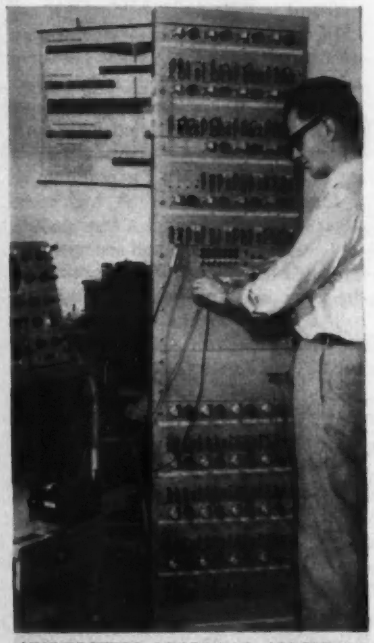
matically recording his progress and charting his reasoning process.

When the student sets up the machine he sees a page of information, on a screen. After studying the material, he must answer a multiple-choice question. To answer, he punches a code number on a keyboard, and a new page of information on his screen either verifies his replies and proceeds with the course, or explains his error and directs him to select another answer. The student's answers, and the time he takes to select them, are automatically recorded for analysis by instructors.

RESEARCH

Mech/elec control

An interdepartmental research and teaching laboratory in the computer and control systems field at the University of Saskatchewan, Saskatoon, Canada, is unusual in that it is under



UNIVERSITY'S LEARNING MACHINE Elementary learning capabilities are claimed for this computer at the University of Saskatchewan

the joint control of the electrical and mechanical engineering departments. It provides research facilities for work on self-organizing and self-adaptive control systems, information and decision-making problems, process optimization and non-linear systems.

At present the laboratory is concentrating on computers in process control and adaptive servo-mechanisms. The techniques of the conditional probability computer program are being developed and applied to the problem of controlling a simple electrical network with interacting controls. Linear programming is being carried out on a digital computer as an approach to process optimization, and the role of the operator as a decision-making element in simple process problems is to be explored. In the field of adaptive servo-mechanisms the immediate goal is to simulate an autopilot control using an analogue computer, and to design a particular non-linear control system incorporating these techniques.

PRODUCTION

Automatic switch-testing

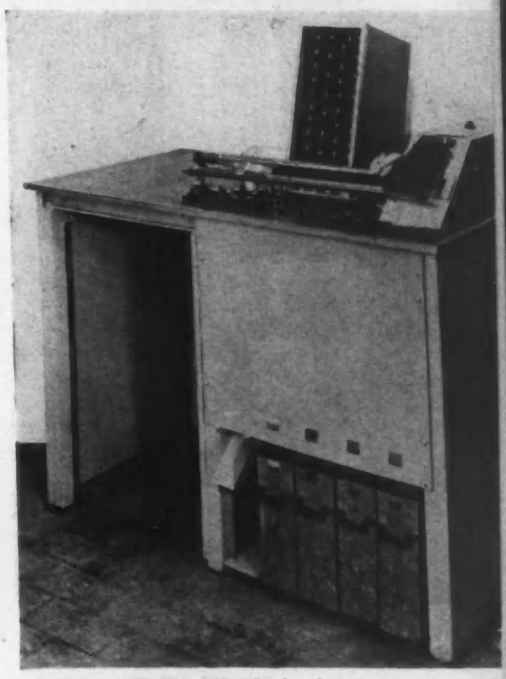
The increasing use of near-flow-line production methods means that the testing of the products of such high-output lines should also be automated. One aspect of this problem has led G.E.C. to install a test rig, based on static-switching devices, for the functional testing of domestic switches being produced at their Witton factory. Four functions of the switches are checked — that the contacts are ' made ' or ' broken ' in the appropriate extreme positions, the position in the travel where ' break ' takes place, and spontaneous return to the ' on ' position when released at the point of breaking contact. The switches are tested at a rate of approximately one a second at normal voltage and 20% current overload.

The basic switching-unit used in the control circuits is the cold-cathode triode, for which a service life of over 10,000 hours is claimed. Logic circuits incorporating these cold-cathode tubes are used for detecting the various types of faults. Final operation of the rejection system is by pneumatic cylinders.

The switches are loaded by an operator into a channel-type magazine, from which they are fed by a weight and pulley system to the testing position in the jig. Testing continues automatically as long as there is a supply of switches in the magazine.

A difficulty arises in sensing the position of the switch under test, as the manufacturing tolerances permit some variation in the position of the operating dolly relative to the case. A mechanical linkage is used which, on sensing the extreme position of the switch, locks the mechanism in such a way that measurements of movement are taken from this point.

This sensing mechanism is driven by a pneumatic cylinder, through a linkage giving a large reduction in movement. Necessary signals giving switch position are derived from the move-



G.E.C.'s automatic testing jig for domestic switches. Control circuits incorporating static switching detect four classes of rejects

ment of the sensing mechanism and applied to the logic circuits, together with signals indicating the presence of a switch in the jig, and whether or not its contacts are ' made '. The cold-cathode-tube circuits are arranged so that any of the faults for which the switches are being tested will open a corresponding trap in the chute through which the switches are discharged. Rejects are then classified into four categories, depending on the nature of the fault.

REFRACTORIES

Damper control at Stein's

A high-temperature kiln at John G. Stein & Co.'s Castlecary Works, refractory manufacturers of Bonnybridge, Scotland, has been fitted with automatic damper control. This corrects any pressure deviations within the kiln by maintaining a balance between gas entering and leaving, and thus gives good combustion conditions, fuel economy and longer kiln life.

The system, which comprises an indicating furnace-pressure controller by Honeywell Controls, and a small reversible electric-motor and gear mechanism, is understood to hold furnace pressure within $\pm$ 0·002 in. w.g. The furnace-pressure controller is of the oil-immersed inverted-bell type, the two bells being suspended on a balance beam. One bell is connected to

The automatic kiln-pressure regulator at Stein's Castlecary Works consists of a Honeywell controller and a motor-actuated damper

furnace pressure through the wall of the kiln, and the other is open to the atmosphere adjacent to the kiln so that pressure measurements are compensated for local ambient conditions.

The controller incorporates two Honeywell Electr-O-Vane units, which do not load the mechanical pressure-sensing system, and these are adjustable about the set point to give any required neutral zone within which the damper is steady. If the pointer moves from the neutral zone, the remote motor actuates the damper to correct the kiln's pressure conditions.

PROCESS CONTROL

£3000 on-line computer

Further details have been released of 'Anatrol'—de Havilland Propellers' inexpensive computer for process control. This does not follow the American fashion for large digital machines in on-line applications, for de Havilland believe that the high cost of such equipment is not in proportion with the degree of responsibility which immediate potential users would be prepared to give it.

The cost of Anatrol has been kept down by two means. First, the use of an analogue-computing technique obviates the need for analogue-to-digital converters at the input, and digital-to-analogue converters at the output, these normally being necessary for digital computers working with conventional control equipment. Secondly, a time-sharing system is used for the mathematical units, and this means that fewer such units are needed. This time-shared computing system is brought into operation repeatedly during a calculation sequence, by a 25-position switch moving at a rate of one step/sec. The mathematics are solved by the units in a series of steps which are controlled by the switch, and the results of each step are stored until brought into the sequence again or fed to the regulating units on the plant. New control signals are fed to the plant at intervals depending on the number of steps required for the solution of the equations. If, for example, five steps are required, the control-signal value may change every five seconds, each value being transmitted continuously until replaced by a new value. The use of the 25-position switch has the effect of making twenty-five times as many amplifiers and multipliers available for any given problem, as in fact Anatrol contains.

Anatrol can receive up to 42 signals from the plant, and can transmit six output signals. It is designed for an overall computing accuracy of $\pm 1{\cdot}0\%$ of full scale—this being considered quite adequate for working with conventional measuring and control equipment. According to de Havilland, any increase in computing accuracy would increase the cost without any significant improvement in the overall result.

Besides normal arithmetical operations, calculations involving power laws, differentiation, and integration can be performed. Where the process cannot be expressed mathematically, an extra unit is available to convert Anatrol into an optimizing computer.

Digital computer control

Optimat, Panellit's optimizing controller, is also coming along rapidly. This is a small-scale single-purpose digital computer for industrial process control. It accepts input signals such as quality, flow, temperature, etc., from the process, and operates on the set points of up to three conventional three-term controllers. The set points are adjusted to give optimum performance of the plant, while simultaneously holding the process within specification limits. Optimat operates by making a small change to the set point of one of the variables and observing the effect of this change on both the specification and the criterion to be optimized. It then acts to steer the plant towards the optimum operating conditions while maintaining the products within specification.

PAPER

Roll-speed indication

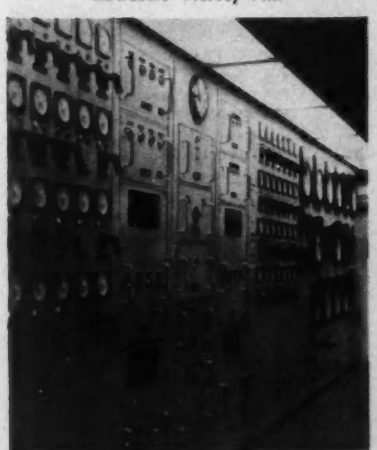
In the manufacture of paper, wet pulp is introduced at one end of the paper-making machine and, the bulk of the water having been extracted, the fibres are brought together as a web, which is then fed through a series of hot and cold rolls. This process makes the web shrink and, to offset this, the rolls—which are of various diameters—must run at varying speeds so that each successive section runs slightly faster than its predecessor, and an even tension is maintained throughout the length of the web. It follows that roll-speeds must be accurately known, for if certain rolls are slow the web may flap or even form a loop; if they are too fast, the web may break.

This difficulty has been overcome at the Mersey Mill of Bowaters United Kingdom Pulp and Paper Mills by the installation of an electronic roll-speed indicator developed in conjunction with Electronic Machine Co. The equipment can be switched to indicate the speed of any pair of rolls of any circumference. The accuracy of speed indication is understood to be $+0$ and -1 ft/min.

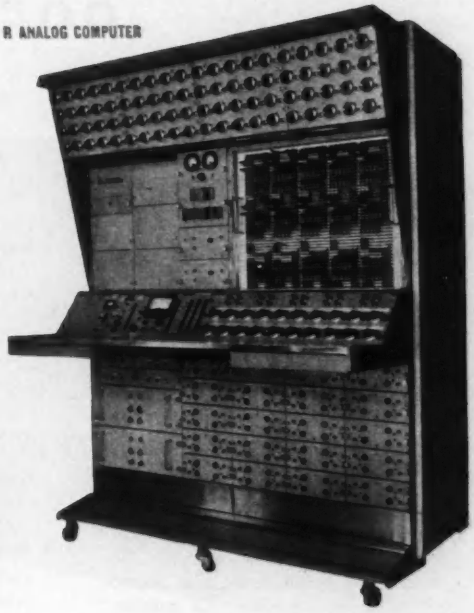
Basically this 'precision paper-draw measuring equipment' consists of a crystal oscillator which feeds 1 kc/s pulses into timers. A low-speed timer counts pulses to produce a timed wave-form which 'gates' the signal from an early set of rolls ('couch') for counting on a four-decade counter. A high-speed timer—a ten-channel, four-decade, unit—whose output can be adjusted from 0 to 9·999 sec, is fed both from the oscillator and from ten different roll-positions on the paper machine, so that each roll signal is counted during a pre-determined time.

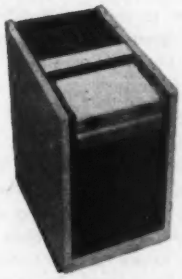
Control understands that Electronic Machine Co. can also provide Digitron devices to indicate the differences in speed between parts of the machine, although this refinement is not employed at the Mersey Mill.

Precision paper-draw measuring machine installed by Electronic Machine Co. at Bowaters' Mersey Mill

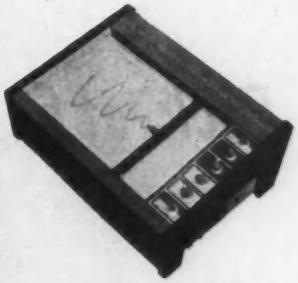


231 R ANALOG COMPUTER





8 CHANNEL RECTILINEAR RECORDER



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TRADE MARK

Pick-off

by 'UNCONTROLLED'

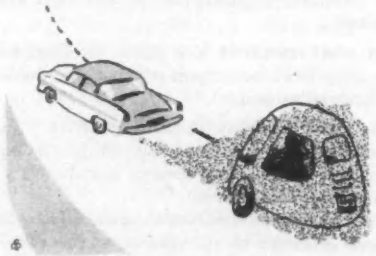
I SEE THAT the Editor is again raising the question of a professional society for control engineers. Having read his leader this month (page 79), I think that he has left out one important matter (perhaps because of shortage of space), a matter that came out rather vividly at a recent meeting of British Ifac Congress delegates. They were preparing for this month's B.C.A.C. *post mortem* on the Moscow conference, and during their deliberations it emerged that the B.C.A.C. itself is terribly underrepresented on Ifac committees. The British point of view (if there is one) is seldom put forward. Ifac committees reach conclusions and make recommendations, but often without the help of a whisper from a B.C.A.C. representative. While I agree that national organization of British control engineers is important, I am sure also that our international standing is a vital plank in the argument for creating a credible professional body. With countries forming commercial clusters all over the place, it is essential for us not only to know what is happening, but to help along events ourselves. Trade practices and the state of the market may not be principal subjects at Ifac committee meetings, but if there are any formative influences working at those meetings then we ought to be in on them.

ONE ALWAYS thinks of Americans as 'go-getters', and of ourselves, by contrast, as conservative and comparatively slow-moving. This form of self-denigration has increased since the war, possibly because of constant political exhortations of the export-or-die type, plus the suggestion that the Germans are rather better at exporting-or-dying than we are. As for the U.S.A., this is the true home of industrial efficiency, and Britain is so far behind that she can never hope to catch up.

Dismal reflexions of this nature are so common that it is refreshing to hear the comments of a young man who knows rather more of American industrial methods than many who merely pontificate from afar. His name is Malcolm Church, and he is a Plessey draughtsman who, because of his outstanding work as an apprentice, was selected to tour the U.S.A. studying American engineering techniques and production methods. He thinks that, although the high degree of automation in American industry gives an *air* of efficiency, the urgency and bustle of British workshops is notably absent.

TALKING OF Germans, I have been dismayed by the rumblings I have heard lately when my ear has been put close to the ground. There seems to be a distinct threat that this country will lose some or most of its computer trade to Germany. Why do we have such a talent for being in at the birth of new industries and out shortly after? Our history is full of this kind of thing, and I hope that it is not going to repeat itself in the computer game.

IF MEMORY serves me aright, it was something over two years ago that an American team came over to show members of the Institution of Mechanical Engineers how automobiles may profitably be regarded as servo-mechanisms. To the best of my knowledge nothing very much was being done along these lines at home, but I gather that things have been set moving: so much so that the I.Mech.E. is beginning to plan a symposium on 'Biomechanics in relation to the automobile'. This sounds a most interesting enterprise and I am looking forward to it.



The automobile as a feedback mechanism

AT THE PRESENTATION of awards in the National Safety Contest (which was sponsored by some thirty major companies), I was disappointed to find few ideas to do with industry as such. Nevertheless, it was heartening to me that over 8600 ideas were actually entered, for their number does at least show an increased concern with this important problem —time lost in industry because of accidents is estimated to be about twenty-million man-days every year. Since the majority of accidents are human in origin, we may hope that the automation of industry, apart from the other benefits that it should confer, will help to cut down this incredible (and frequently tragic) waste of manpower.

THE EDITOR'S STORY last month about the first prize in an American competition being one week's stay in Moscow and the second prize two weeks' stay there reminds me of Chesterton's remark about beer: 'one pint is just right; two pints are one too many; and three pints are not half enough'. The magazine *Which?*, now becoming more and more well known, was reporting on beer only last month. I have sometimes heard readers suggest that *Control* should give *Which?* type reports in its periodic surveys of equipment. Manufacturers of some of the more popular hardware might be in for a few mild and bitter surprises if their products fared as poorly in *Control* surveys as did some of the best-known ales and lagers in *Which?*

THERE IS TO ME a peculiar savour of common sense and robust honesty in so many of Hugh Clausen's opinions. Readers of *Control* are of course familiar with his work, and some of you who are top people may have seen his letter in *The Times* recently. Answering the question: 'What is really wrong with British exports?' he found the cause in profit-grabbing enterprise. 'We must realize', he urged, 'that the *product* is the thing that counts. If proper attention is paid to all aspects of this—including selling it—the *profit*, as a kind of by-product, is almost automatic.'

But try telling that to engineering businesses when they are run by accountants!

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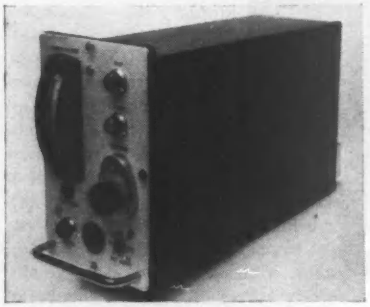
TRIP AMPLIFIER

indicates temperature

This unit is a transistorized temperature trip-amplifier, which has a scale indicating the temperature over a range prior to the set-point. The incoming signal



Accurate reference-voltage

from the thermocouple is compared with a reference voltage, which may be set to an accuracy of 0·1% of the instrument range.

Trip-point range is standard at 0–30 mV, and the on-off differential is given as less than 30 μV independent of trip level. The trip and subsidiary alarm relays are fitted with platinum contacts rated for 250 V a.c., and each has four change-over contacts brought out to two 12-way connectors on the rear panel. Made by Bailey Meters and Controls.

Circle **No 531** on reply card

PRECISION RESISTORS

low temperature coefficient

Resistors having tolerances at 20°C of 1%, 0·5%, 0·25%, or 0·1%, are available from Alma Components. Temperature coefficient of all ranges is quoted as $\pm$ 0·0004%/°C, and drift is less than $\pm$0·05% for the first 1000 h, thereafter negligible. Type C1 (1-W), C2 (½-W), and C4 (¼-W), have resistance ranges of 100 Ω–300 kΩ, 100 Ω–120 kΩ, and 100 Ω–80 kΩ respectively.

Circle **No 532** on reply card

VALVE VOLTMETER

10 MΩ input-impedance

An improved version of Advance Components VM 77 measures from 100μV (minimum readable deflexion) to 300V a.c. in twelve ranges, with a frequency coverage from 10 c/s to 5 Mc/s. The 3-in. meter has an anti-parallax mirror, and is calibrated in volts r.m.s. and decibels referred to 1 mW fed into 600 Ω. Accuracy is given as $\pm$3% f.s.d. from 15 c/s to 2 Mc/s, and $\pm$2dB up to 4·5 Mc/s. Normal input impedance is 10 MΩ, 20 pF, with less than 10% variation between ranges.

The basic circuit is a four-stage transistor amplifier, with bridge rectification for the meter. Used as an amplifier, gain up to 5 Mc/s is 1000 (60 dB), adjustable in 10-dB steps. The h.t. supply is stabilized to $\pm$1½%, and the unit will work from 100-125 or 200-250 V a.c. mains.

Circle **No 533** on reply card

LEVEL INDICATOR

capacity-operated

A feature of a continuous level indicator is that the instrument may be mounted up to 100 yd. away from the probe. The circuit employs a crystal-controlled oscillator, which is connected to the probe or transducer by a matched transmission-line. A capacity change of 10 pF will give full-scale deflexion on a 1-mA meter, or a change of 5 V d.c. is available. This voltage is negative with respect to earth so that it can be used to drive a d.c. amplifier.

For applications requiring extreme sensitivity, provision may be made for a 1-mA change in output to represent a change of 0·03 pF. The Contimitor is made by Electronic Machine Co.

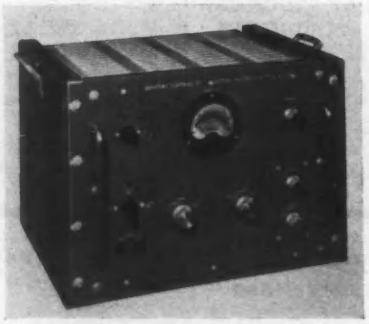
Circle **No 534** on reply card

MOTOR AND CONTROLLER

reversible rotation

A unit by Servomex consists of a motor and controller designed to give motor speeds between 0 and 7500 rev/min, with a minimum torque over the entire range of 70 oz in. The motor shaft carries a linear generator which has a voltage output proportional to speed, and this is compared with a voltage reference inside the controller. Any difference or error is amplified in a servo-amplifier, and applied to the field-coils of the motor so as to correct the speed.

Wide speed-range



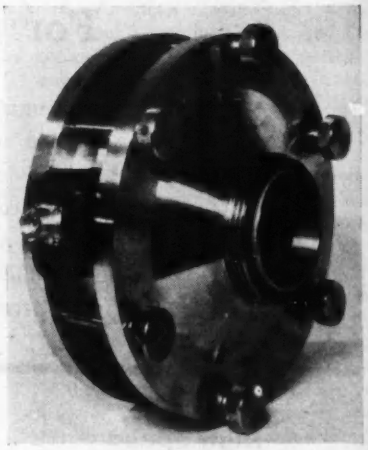
The MC.47 will provide tolerably smooth running down to 10 rev/min, and a meter mounted on the control panel gives an indication of speed to an accuracy of $\pm$1·5% f.s.d. Scale ranges are 10,000, 3000, 1000, and 300 rev/min. Acceleration, with flywheel mounted, is 60,000 rev/sec², or without flywheel, 420,000 rev/sec². The unit may be used for torque measurement, using a 150-V, d.c. meter across the terminals provided. A 50-c/s mains supply is required, 200 to 250 V.

Circle **No 535** on reply card

FLOWMETER

constant-amplitude output

An electro-magnetic flowmeter by Measurement Ltd, is designed so that each cycle of the piston displaces the same



Accurate, rugged

volume of fluid. The pick-up unit gives a pulse output, the amplitude of which is constant regardless of flow-rate, and which may be fed to an electromagnetic counter or similar device.

Four models of the Unipulse are made, with ranges between 5–300 and 100–12,500 gal/h; they may be constructed in gun-metal or stainless steel. With constant head or constant pump-output, this unit may be calibrated to within $\pm$ 0·25%.

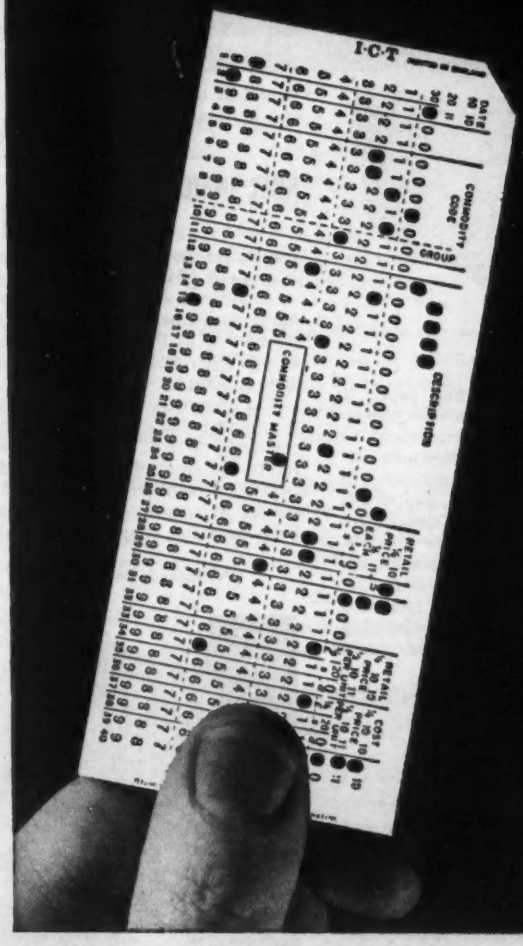
Circle **No 536** on reply card

TRANSISTOR OSCILLATOR

robust, portable

An *RC* oscillator has five frequency ranges between 1·5 c/s and 150 kc/s in decade steps. Accuracy is given as $\pm$ (3% + 0·15 c/s) at 25°C, and short-

I·C·T 40-COLUMN PUNCHED CARD SYSTEMS can help your business



WHAT DOES 40-COLUMN MEAN?
It means a punched card data processing system using small cards which record data in 40 columns—quite sufficient for a large number of jobs.

If you're considering a data processing system, see what 40-column machines will do for you. They are more than earning their keep for many thousands of organisations: firms operating with as few as 12 people to concerns employing over a thousand.

What I·C·T 40-column equipment can do for YOU

It will mechanise your sales and purchase accounting, and produce your statistical records. Other everyday jobs it will tackle include stores and stock control, invoicing, payroll, hire purchase accounting, expenditure control and costing. It will help you wherever you need accurate accounting and statistical information quickly.

The equipment is readily available; it is easy to put in and simple to use.

I·C·T 40-column equipment can grow with your firm

The basic machines—auto punches, sorters and tabulators—may be all you want at the moment. But you can always add summary, reproducing and electronic calculating punches, interpolators and interpreters. And you can increase card capacity by 25% without spending a penny more.

Write to us at I·C·T—*now*.

ICT

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149 Park Lane, London W1
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I·C·T manufacture 21-, 40-, 80- and 160-column punched card machines, as well as small and medium-sized computers.

For on-site investigation

term drift is less than ± 0·05% after the first thirty seconds of operation.

Output, into 600 Ω, is continuously variable up to 2·5 V; variation of output-voltage with frequency is less than 0·03 dB on each range. Temperature range is − 10°C to + 45°C. The TG 150 M, made by Levell Electronics, weighs about 6 lb including self-contained batteries. Also available is the TG 150, which has no output meter but is otherwise identical.

Circle **No 537** on reply card

PHASE METER

very low frequencies

A phase meter measures phase angle in degrees, within the frequency range 0·0001 to 1·0 c/s, between two sinusoidal or non-sinusoidal voltages. Designed for vibration and servo-mechanism investigation, its phase-angle range is 0–360° in six steps of 60°. Amplitude range is 1–30 V r.m.s. sine wave, and accuracy is given as ± 1° (0·001–0·1 c/s), or ± 2° (0·1–1·0 c/s).

The 335-A, made by Acton Laboratories (U.S.A.), will accept sine or complex waves provided that no d.c. component is present; applied signals must not have more than one positive-going or negative-going zero axis crossing per cycle. Power supply needed is 105–125 V a.c., 60 c/s; consumption is about 120 W.

Circle **No 538** on reply card

SOLENOID-CONTROLLED VALVES

air-operated

An extension to an existing range of solenoid-operated valves has increased maximum available size to 3 in. The compressed-air supply is controlled by a small three-way solenoid valve mounted integrally with the main valve. When the solenoid is energized, air enters the piston chamber, and the piston opens the main valve. When the solenoid is de-energized, the air supply is shut off and the pressure between the main and solenoid valve is exhausted to atmosphere. The main valve then closes under spring pressure.

Made by Ether, one of the principal functions of the A.S.V. series is the control of high viscosity fluids.

Circle **No 539** on reply card

OSCILLOGRAPH

12-channel, direct-writing

An oscillograph capable of recording at frequencies up to over 1000 c/s has a choice of eight paper-speeds from 5 in/min to 150 in/sec. It employs an ultra-violet light source and pencil-type galvanometers, and is claimed to give a clearly defined trace at writing speeds in excess of 12,000 in/sec. The recorder is normally supplied as a twelve-channel unit, but fifteen galvanometers are fitted in the magnet block, the extra three being available for marking datum lines or as extra signal channels if necessary.

Since any trace may sweep the whole

Fast writer

6-in. width of the recording paper, a 'marker' is included in each for identification. A trace interrupter, geared to the paper drive roller, interrupts the light from each galvanometer in sequence and causes a $\frac{1}{16}$-in. gap at 2-ft intervals irrespective of chart speed. Five galvanometers are available for the Savage and Parsons RG32-12/15, with sensitivities from 450 μA/cm (resonant frequency 500 c/s) to 16 mA/cm (resonant frequency (3100 c/s). Special clamping arrangements allow easy and rapid changing of galvanometers.

Circle **No 540** on reply card

DATA AMPLIFIER

precise amplification

Designed for precise amplification of microvolt signals, a differential amplifier made by Blackburn Electronics has a completely floating input of 3-MΩ impedance with a common-mode rejection-ratio of 10^6:1 at d.c. (i.e. the ratio of differential signal to in-phase signal for a given output). The gain is switchable in five stages from 10 to 1000, and linearity is 0·1% with a maximum out-

Sensitive, accurate

put swing of ±10V at 0·5A. Total noise and drift is less than 5μV r.m.s., with a rise-time of 10 msec.

The BIE 362 weighs about 20 lb, and has built-in power supplies which will operate from 115- or 240-V a.c. mains.

Circle **No 541** on reply card

A.C. SERVO-MOTOR

1/10 h.p. nominal

A size-45 a.c. servo-motor is to be produced by Evershed. Designed for operation from 50- to 60-c/s supplies, the following windings are available: reference phase, 115 or 230 V a.c.; control phase, 115, 230 or 500 V a.c. (these windings may be centre-tapped).

The stalled torque is 80 oz in, and the no-load speed is 2930 rev/min for 50-c/s operation. Input at stall is 100 W (120 VA) per phase. Dimensions and weight of the Fay are 4½ × 4½ × 8½ in. and 28 lb respectively.

Circle **No 542** on reply card

NULL INDICATOR

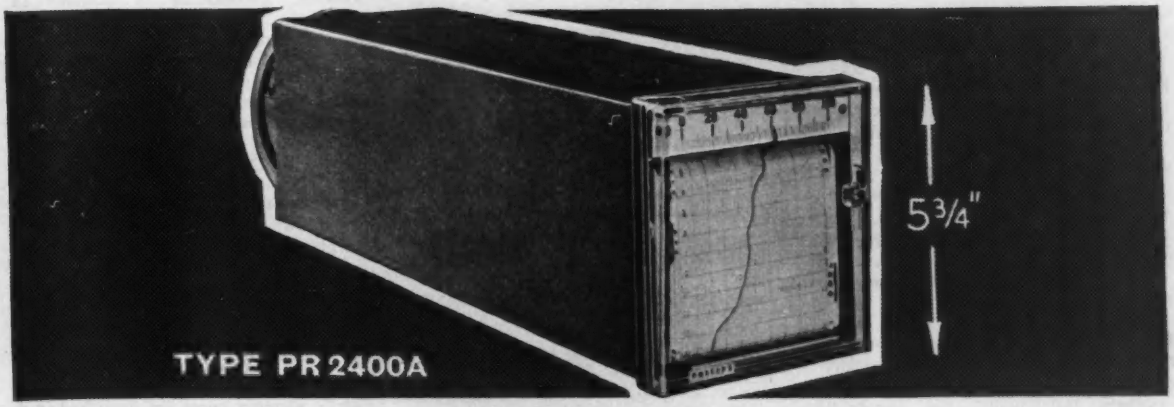
robust, sensitive

Insensitive to vibration or level, the Honeywell 104 Wl-G is designed for use in conditions where a standard galvanometer would be unsuitable. It has a response-time of 0·5 sec, and a sensitivity of 1 μV/mm or 10^{-9} A/mm. Input resistance is 100Ω.

The operation is briefly as follows: a d.c. input is fed to a chopper circuit and converted to a.c. This is amplified and fed to the grids of a double-triode grid-controlled rectifier, the anodes of which are fed in opposite phase to one another from the mains supply via a transformer.

Withstands rough handling

PHILIPS
MINIATURE RECORDER



FEATURES Small panel space of 144 x 144 mm (approx. 5¾" x 5¾") · Reliable null-balancing potentiometer system · Easily interchangeable ranges · Transistorized plug-in amplifier with printed wiring · Unique chart-winding system · High indicating speed and critical damping · Scale calibration for mV or all conventional thermocouples · Completely mains operated.

RECORDING SECTION Strip chart, width 100 mm, length approx. 9 m. The chart is wound into an exchangeable casette. Visible length of 100 mm. After opening the door the chart can be pulled out over a length of 80 cm. Chart returns automatically into the casette.

CHART-SPEED With built-in gear box 3 different speeds can be selected: 10, 20 and 60 mm/h. Can be supplied with electro-mechanical clutch so that by means of external switch, chart movement can be accelerated by a factor of 60.

This photograph shows the lighter weight and compact size of the plug-in transistorized amplifier.

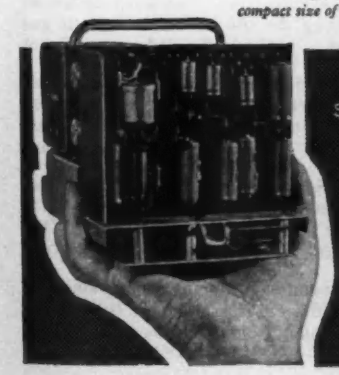
Miniature mV-Recorder

MINIMUM SPAN 5 mV · MAXIMUM SPAN 250 mV
ACCURACY 0·5%; the accuracy can be maintained after exchange of range box.
REPRODUCIBILITY 0·2% of span · SCALE LENGTH 100 mm.
STABILITY 10% mains variations have an influence of less than 0·1%
BALANCING SPEED Less than 1 sec. for full scale deflection; damping critically adjustable.

RECORDING With flexible capillary stylus supplied from sealed ink container mounted under measuring carriage. Line thickness approx. 0·3 mm.

CONSTRUCTION Sheet-metal case in grey hammertone with all plastic door. Front dimensions 144 x 144 mm; depth 510 mm; panel opening 138 x 138 mm. (5¾" x 5¾"—20"—5½" x 5½").

PRODUCT OF PHILIPS, EINDHOVEN, HOLLAND



SOLE DISTRIBUTORS IN U.K

RESEARCH & CONTROL INSTRUMENTS LTD

Instrument House · 207 Kings Cross Road · London · W.C.1.

Telephone: Terminus 2877

(RCL0009)

The polarity of the input determines the phase of the amplified a.c., and since the chopper is mains-synchronized, this in turn determines which anode of the g.c.r. will conduct when the grids are positive. When one of the anodes conducts, the relevant cathode becomes more positive, and a charge is built up across a capacitor connected between the two cathodes. This charge is measured by the indicating meter. A diode limiter is connected between the cathodes to prevent overloading of the meter.

Circle **No 543** on reply card

QUICK LOOKS

Plug-in dial timer. Designed for rapid replacement in installations where down-time must be minimized, the Atcotrol 305 is available for a.c. or d.c. operation. Time ranges for 115-V, 60-c/s operation are from 15 sec to 60h; for 48-, 125- or 250-V d.c. operation, ranges are 30 sec to 240 min. Made by Automatic Timing and Controls (U.S.A.).

Circle **No 544** on reply card

Portable tachometer. Two versions of this transistorized mains- or battery-operated instrument are available from Southern Instruments: one covers 0–30,000 rev/min, the other 30,000–300,000 rev/min. These instruments will operate from photo-electric or magnetic pick-ups; overall accuracy is 1·5%.

Circle **No 545** on reply card

Analogue reactor computer. The M.A.R.C. analogue computer, made by Miles Electronics, combines special purpose equipment for reactor design studies and general purpose computing units.

Circle **No 546** on reply card

Regulated power supply. A compound-regulated dual unit has two separate supplies on one chassis, using a common reference. Outputs are +300 and −300 V d.c. each rated at 500 mA. Load regulation is less than 1 mV d.c., with a transient recovery time under 2 μsec. The Philbrick (U.S.A.) Model R-500 requires a mains input of 105–125 V, 50–60 c/s.

Circle **No 547** on reply card

Wave generator. Designed for testing servo-systems, Feedback's TWG 100 will generate square, sine and flat-topped 'triangular' waves over the range 0·03–30 c/s in six switched ranges. Five output-levels are provided: 40, 30, 20 and 10 V_{p-p} fixed, and 0–5 V_{p-p} steplessly variable; voltage accuracy is ± 5%.

Circle **No 548** on reply card

Air and hydraulic cylinders. A range of heavy-duty cylinders is announced by S-P Manufacturing (U.S.A.). Pressure ratings are 200 lb/in² (air) and 1000 lb/in² (hydraulic). Nine bore sizes are available ranging from 1¼ to 8 in; temperature range is −20 to +150°F.

Circle **No 549** on reply card

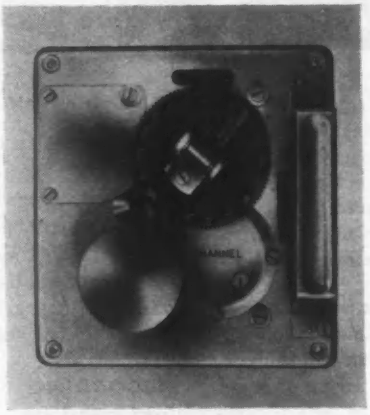
Oscilloscope. The model 33a, of Taylor Electrical, has a hard time-base covering 2 c/s to 100 kc/s either free-running or triggered. Horizontal and vertical amplifiers with push-pull output are provided, the vertical amplifier having a frequency range up to 60 Mc/s.

Circle **No 550** on reply card

Radiation monitor. This unit is made by Plessey Nucleonics for measuring radioactive contamination in bulk quantities of milk (standard 10-gal churns). It consists of a probe sensitive to both beta and gamma radiation, and a waterproof indication-unit directly calibrated in terms of tolerance levels. It will work from 12 V d.c. or standard 50-c/s mains.

Circle **No 551** on reply card

Rotary position-selector. Designed to rotate a shaft to any of twelve independently-set positions with an accuracy within 6 minutes of arc, the Plessey type 9008 is available for operation from



12-48 V d.c. with a torque of either 35 or 60 oz in. The selected position is shown on the front of the unit, and a built-in switch can be used to confirm the position to a remote control site.

Circle **No 552** on reply card

Multi-range meter. The model 105a by Taylor Electrical is a general purpose meter with a sensitivity of 20,000 Ω/V. It has 21 ranges, including resistance from 0–20 MΩ in three ranges.

Circle **No 553** on reply card

Blood pH-meter. Said to be the first direct-reading meter designed solely for the measurement of blood pH, the Electronic Instruments type 48A has a discrimination of 0·005 pH. Range is 6·6–8·0 pH, and zero stability is better than 0·005 pH in 12h. Manual temperature compensation is provided from 0–42°C in 0·5°C steps.

Circle **No 554** on reply card

INDUSTRIAL PUBLICATIONS

'The A.B.C. of electronic brains' is the title of a booklet containing a series of B.B.C. talks by Elliott Automation's Leon Bagrit. Circle **No 555** on reply card

Control board components are described in Technical Description No. 403 from G.E.C.'s Engineering Group.

Circle **No 556** on reply card

Banking Automation is outlined in National's booklet on their 'Post-Tronic' machine.

Circle **No 557** on reply card

Flame failure and lighting-up-sequence controllers for air-blast tunnel burners are described in data sheet FST from Elcontrol. Circle **No 558** on reply card

Level control. Details of Lancashire Dynamo's transistorized level control are given in leaflet No L.5.

Circle **No 559** on reply card

Water-level indicator. Catalogue No 150 from James Gordon describes their Igema boiler-water-level indicator.

Circle **No 560** on reply card

Ferrite memory cores are described in a series of leaflets available from Telemeter Magnetics (U.S.A.).

Circle **No 561** on reply card

Machine tool drives are illustrated in a comprehensive 80-page catalogue from A.E.I. Circle **No 562** on reply card

Solid-state logic elements. Panellit's Minilog system is shown in leaflet ML.1.

Circle **No 563** on reply card

'Data handling systems' is the title of a descriptive leaflet from Armstrong Whitworth Aircraft.

Circle **No 564** on reply card

Electric lifting magnets are the subject of G.E.C.'s Technical Description No 379. Circle **No 565** on reply card

'Statistical review of the world of Industry, 1959,' is the title of a 24-page booklet from British Petroleum.

Circle **No 566** on reply card

'Precious metal contacts' is the title of a catalogue from Engelhard Industries detailing the use of various metals and alloys. Circle **No 567** on reply card

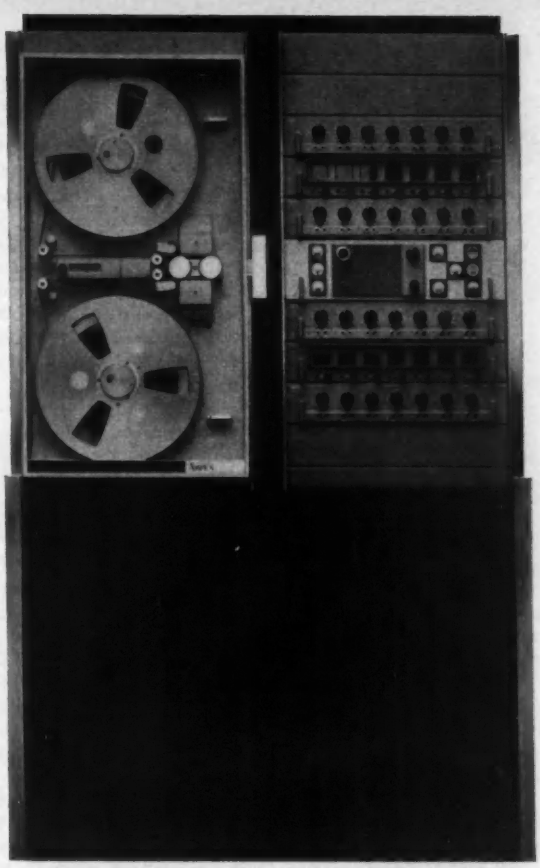
Overhead Runways for transportation of goods and raw materials are described in Section 6 of Coburn's main catalogue.

Circle **No 568** on reply card

Radiation counter. An automatic sample-changer by Nuclear Chicago is illustrated in a leaflet from Continental Distributors. Circle **No 569** on reply card

Horizontal co-ordinate drilling-machine. The 6 ft. × 6 ft. Autonomic is described in a leaflet from Archdale.

Circle **No 570** on reply card



The AMPEX FR-600 is an advanced-design data recorder with twice the capacity of conventional recorders. Most analogue recorders can only record 24 minutes of 100 Kc data on a 14-inch reel of 1 mil tape. The FR-600 will record 48 minutes of the same data on the same reel of tape. The reason – greater bandwidth at a given speed . . . 125 Kc at 30 ips, for example. Many data-runs are 30 minutes or longer, requiring a stand-by recorder to pick up where the first leaves off . . . an expensive price for a few extra minutes of recording time. The FR-600 literally does the work of two conventional machines by enabling double record time for any given bandwidth, or double bandwidth for any given record time . . . 250 Kc at 60 ips, for example. Another cost-saving feature is the tape shuttle which automatically scans any portion of the tape, eliminating the need for a separate loop recorder. Modular plug-in, solid-state electronics warm up in less than 10 minutes, and FM amplifier drift is less than one percent in 24 hours. Other advanced features of the FR-600 include pneumatic tape guiding, tension sensing and control, adjustable search speed and fourteen miniature monitor oscilloscopes. For complete information write Ampex Great Britain Limited, Arkwright Road, Reading, Berkshire, England. AMPEX

Book Reviews

Fluid power

Fluid Power Control *by* **John F. Blackburn, Gerhard Reethof, J. Lowen Shearer and others.** *John Wiley & Sons, New York. Chapman & Hall, London. 1960. 710 pp. £7.*

This is a book which should dominate its subject for ten years to come. It covers for the first time in one volume most of the important topics of hydraulic and high-pressure-pneumatic proportional control and brings together comprehensive summaries of many of the papers from M.I.T. which have appeared in the Transactions of the A.S.M.E. Some of the M.I.T.'s well-known basic work is still left to reference. This only emphasizes the need for a second such volume and the unique nature of the first, its rarity (as well as length) being no doubt reflected in its desperately high price. The twenty chapters individually tend to a self-sufficiency which makes for easy reading at the price of sometimes severe overlapping. But mistakes are few in a complex piece of well-produced printing and the book is certain to be highly valued despite its faults of presentation.

Well presented in the first three chapters are: the circumstances which favour fluid rather than electric power, the selection of a working fluid, and the fundamental characteristics of fluid flow. The chapter on pump efficiency relations and the thermal wedge principal of lubrication appears to fill a vacant space labelled 'Power Supplies', but is nonetheless useful and interesting in isolation. The book then settles to its main topics with six crisp chapters on oil and pneumatic proportional control valves and two on the nature of the loads which they must control, building up theory and practice from first principles. By contrast Chapter 11 disposes of torque motors in one fell swoop. Though inherently well written, most engineers will find it excessively short and out of character. Two of the other chapters, 12 and 13, are also largely devoted to electrically signalled control valves.

After a summary of feedback control analysis methods, the remaining six chapters discuss valve-controlled rams and motors. The discussion is largely analytical but illustrated by extensive examples. Wherever possible, interactions are explained in terms of feedback, and the derivations are in a style which will be familiar to all servo-mechanism engineers. Although much of the redundancy occurs here, the book's last third makes a strong and valuable contribution to a whole which has the makings of a classic work. P. D. BOYER

Computers

Electronic Computers—Principles and Applications *by* **T. E. Ivall.** *Iliffe & Sons, London. Philosophical Library, New York. 1960. 263 pp. £1 5s.*

This second edition shows, in the extent of its re-writing and the swiftness of its appearance, how quickly computers are progressing both in their technical refinement and in their popularity with the public. Mostly concerned with the 'innards' of digital and analogue computers, the book is unmathematical in presentation and designed for technicians and others who prefer this kind of descriptive approach. The story is clearly and pleasantly written. It begins with some history, discusses general principles, and then goes into more detail on circuits, components, equipment and applications. A speculative final chapter is devoted to 'Computers of the Future'.

Illustrations are plentiful, both in line and half-tone, and the format is uncluttered. The index could be considerably improved A. J. D. ELLIS

Analogue and Digital Computers *edited by* **A. C. D. Haley** *and* **W. E. Scott.** *George Newnes. 1960. 307 pp. £2 10s.*

Written by a panel of contributors—on the excellent advice of Dr Say—this book is designed for students new to computers. The editors acknowledge in their preface that there are several omissions, but express a belief that the background given by the book will be helpful in preparing readers for pursuit of the latest developments: they are probably right.

The operation, application and design of analogue systems is covered first, and the book then goes over to digital computers, concerning itself with number representation, operation, componentry, storage, input-output equipment, and programming.

The general presentation of the book is satisfactory, and the index is quite good. There is a useful list of references given with most of the ten chapters. L. P. REEK

Instruments

The Instrument Manual *edited by* **J. T. Miller.** *United Trade Press. 1960. 842 pp. £5 5s.*

A useful book in the office, and *perhaps* a good leaving present for someone changing his job, this is still not quite the sort of volume that one can advise the engineer to lavish five of his own guineas upon. The book is uneven in the quality of its content—which is perhaps only to be expected with so many different contributors—and the production is not worthy of a standard work of reference. This third edition is along substantially the same lines as the second, possibly the biggest change being that analogue computers have ousted navigational instruments (though digitals have been left out). Automatic process control has a chapter to itself, and there is additional material on the control of particular parameters in the specialized chapters. Bias is toward process work, and engineers concerned with kinetic control are less well served. There is a good index, but one must thumb one's way back through a hundred pages of advertisements to find it. A bibliography and buyers' guide appear at the end of each section.

A.E.E.

Similarity

Similarity and Dimensional Methods in Mechanics *by* **L. I. Sedov.** *Cleaver-Hume Press, London, for Infosearch. 1959. 363 pp. £5 5s.*

The fourth edition of a book first published in Moscow in 1943, this well-produced but expensive volume is the latest in a series under the general heading of 'Russian Science'. A surprisingly high proportion of the other titles in the series relate closely to the work of control engineers, and this may be a reflexion of the importance ascribed to this subject in the Soviet Union. The present text is rather on the fringe of such interests, but will serve well those who would like to gain an insight into the principles and applications of dynamical similarity. Those who can afford the time (and the money) will find it interesting to study the classic mechanical engineering approach to the problems of simulation. Dimensional analysis is of course a fundamental technique, and not restricted to the interpretation of scale-model tests on aircraft, ships and dams. In fact the author goes much further afield in choosing his material, and applies himself most interestingly to astrophysical problems. I. N. KENTON

Literature Received

Computer Engineering *by* **S. A. Lebedev.** *Pergamon Press Ltd. 1960. 184 pp. £3 3s.* ★ 701

A Constant Level Device for a Super-Cooled Liquid Nitrogen Condensing Head *by* **J. Chadwick** *and* **K. J. Taylor.** *U.K.A.E.A. 1960. 8 pp. 1s. 9d.* ★ 702

Introduction to Modern Network Synthesis *by* **M. Van Valkenburg.** *John Wiley & Sons, New York, Chapman & Hall, London. 1960. 498 pp. £4 14s.* ★ 703

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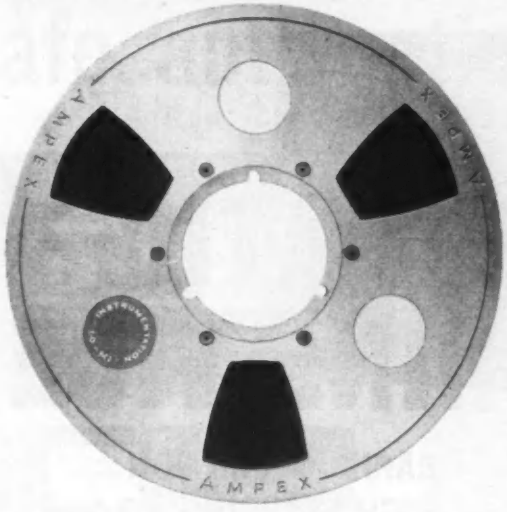

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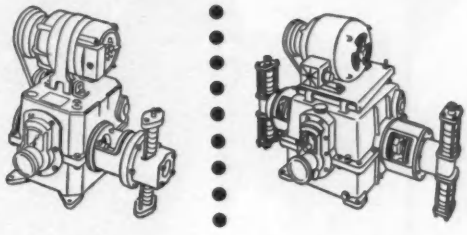
The gearbox

is the very heart of a metering pump



Type 'M' Type 'G'

This Varistroke Gear Box is used in the Metripump type 'M' and Metripump 'G' in both ranges of which a wide variety of pump heads is available. By reducing the maximum delivery pressure as the ram diameter—and thus the capacity—is increased, an even load is maintained on the gear box. All working parts are totally enclosed in the Varistroke Gear Box and operate in an oil bath so that no external lubrication is required. If you would like to know how profitable the right kind of metering pump can be, ask us to send a representative who will explain the advantages quickly and lucidly.

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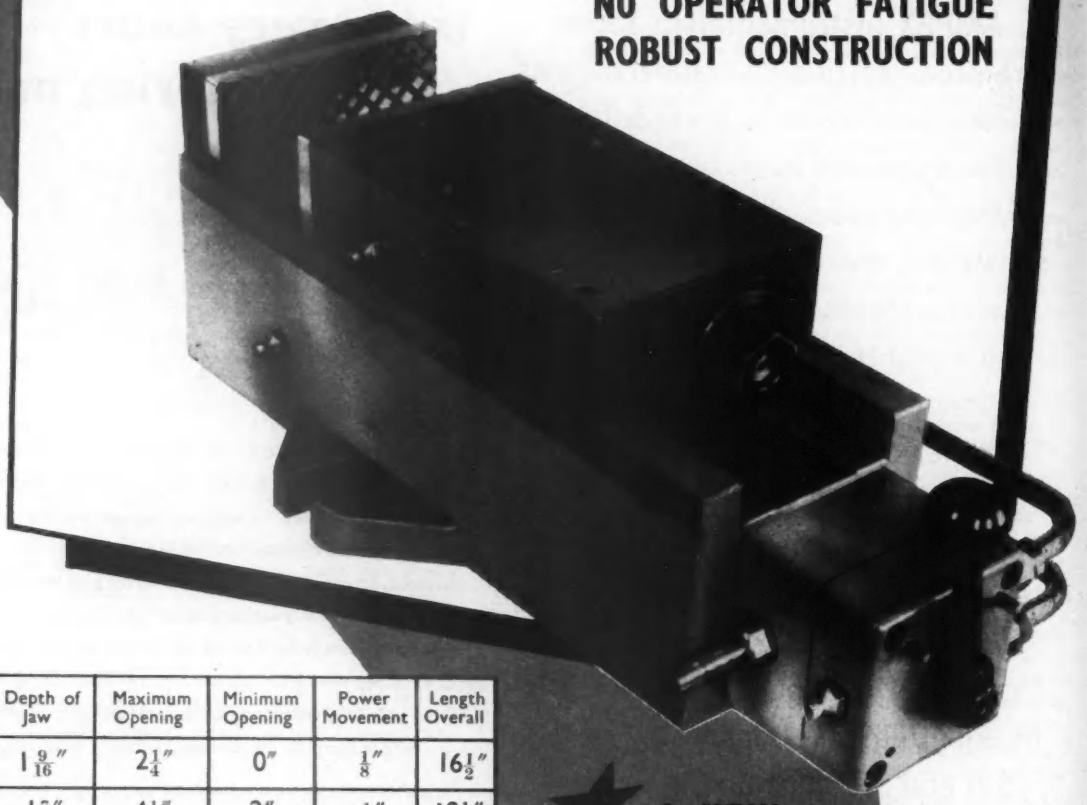

Sizes	Depth of Jaw	Maximum Opening	Minimum Opening	Power Movement	Length Overall
4″	$1\frac{9}{16}$″	$2\frac{1}{4}$″	0″	$\frac{1}{8}$″	$16\frac{1}{2}$″
6″	$1\frac{7}{8}$″	$4\frac{1}{4}$″	2″	$\frac{1}{8}$″	$19\frac{1}{2}$″

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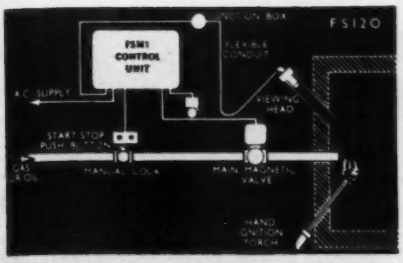
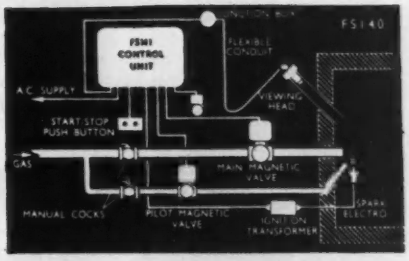
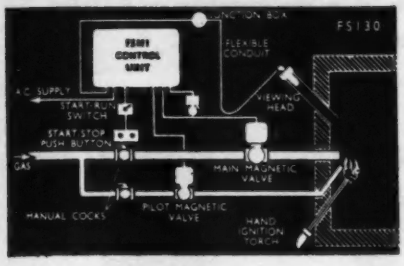
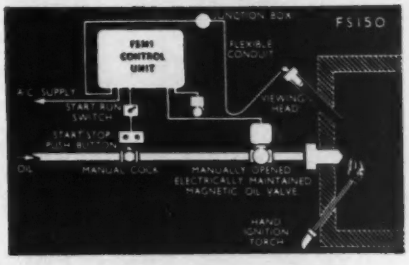
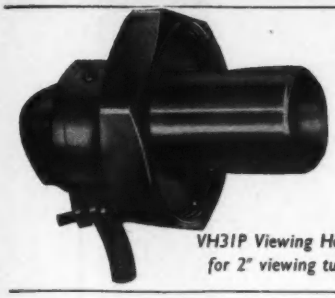


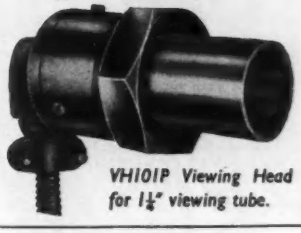








VH31P Viewing Head for 2" viewing tube.



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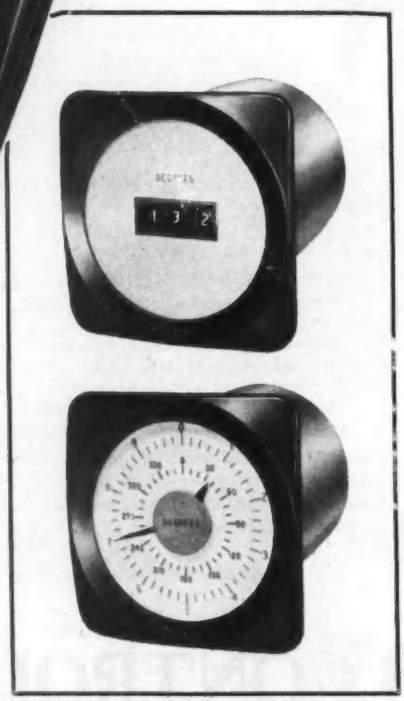

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1. Dual purpose tube for fuse housings. Outer wall of synthetic resin bonded paper, with inner wall of Vulcanized fibre. Combining the highest qualities of electrical insulation, and arc resistance.

5

2. Round section of Bakelite tube. Produced in bonded paper for electrical insulation, and in bonded cotton fabric for electrical resistance plus a high degree of tensile strength. Both can be machined and threaded.

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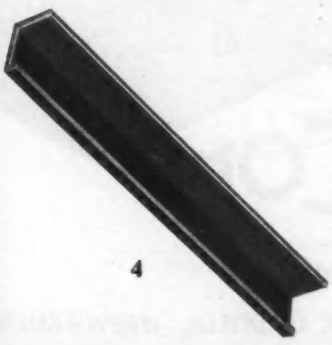

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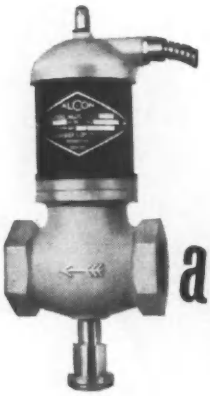

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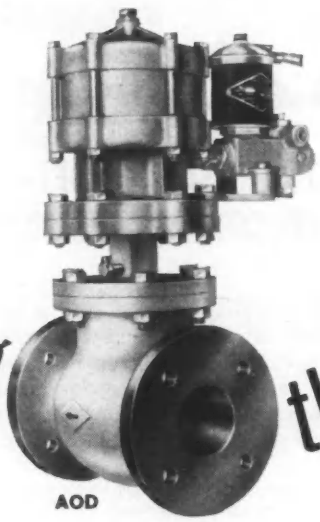
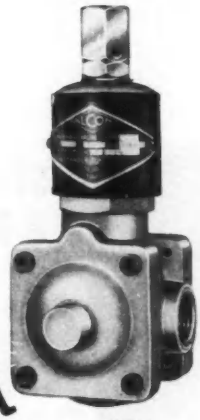
anything that flows



AOD



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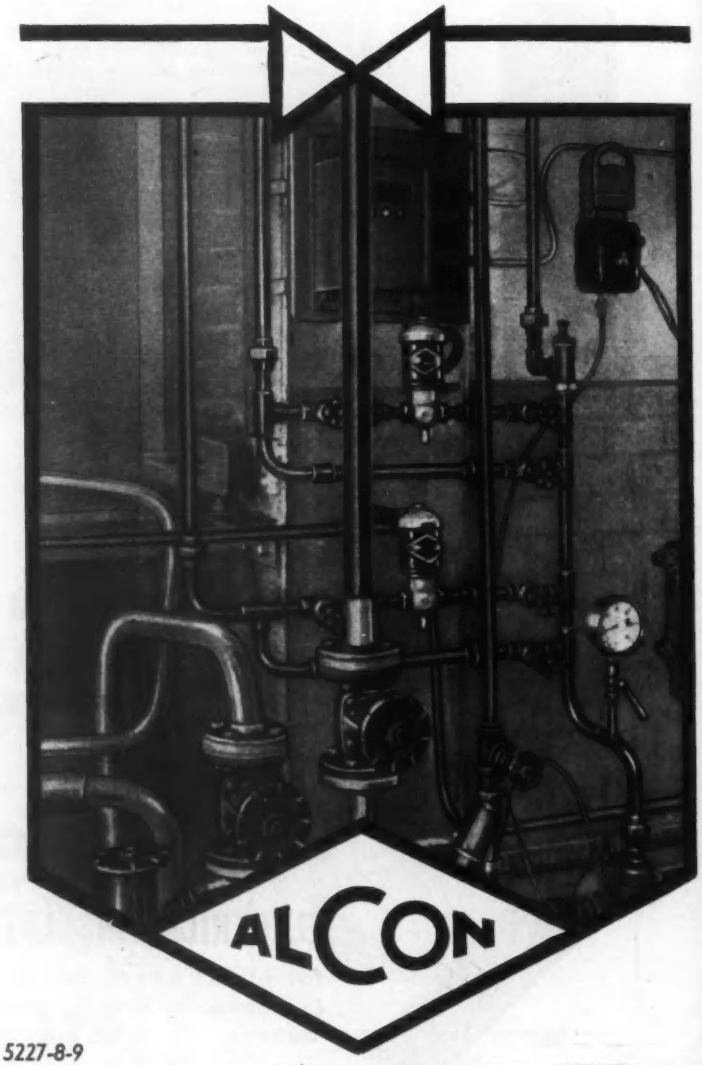

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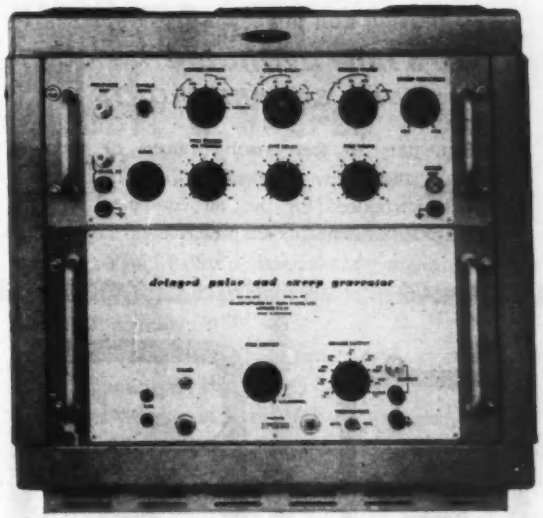

A versatile pulse generator designed to meet the need for a comprehensive instrument covering a wide range of pulse work. Four main facilities are provided: a pre-pulse, a main pulse delayed on the pre-pulse, a negative going sawtooth and a fast rising pulse formed from a pure line.

BRIEF SPECIFICATION

Period

Continuously variable from 0·9μsec to 1·05sec i.e. 0·95c/s to 1·1Mc/s. Accuracy ±5%.

Pre-pulse

40mμsec. 8V peak in 75Ω, positive going.

Main pulse

Width: Variable from 0·09μsec to 105msec ±5%.

Amplitude: Control gives 4:1 attenuation of each of four maximum outputs as follows:

5V max in	75Ω	rise time 10mμsec
10V max in	150Ω	rise time <20mμsec
25V max in	600Ω	rise time <40mμsec
50V max in	1000Ω	rise time 50mμsec

Polarity: Positive or negative going.

Accuracy: ±2%.

Delay

Conclusion of pre-pulse to advent of main pulse, delay variable from 0·09μsec to 105msec. Accuracy ±5%.

Sweep

D.C. coupled negative going sawtooth same width and delay as main pulse.
15V peak max.

Cable pulse

Obtained from short circuited pure line.
One positive and one negative going pulse coincident with main pulse.
25mμsec wide 3V max in 75Ω, rise time <8mμsec.

Sync, trigger or single shot facilities provided.
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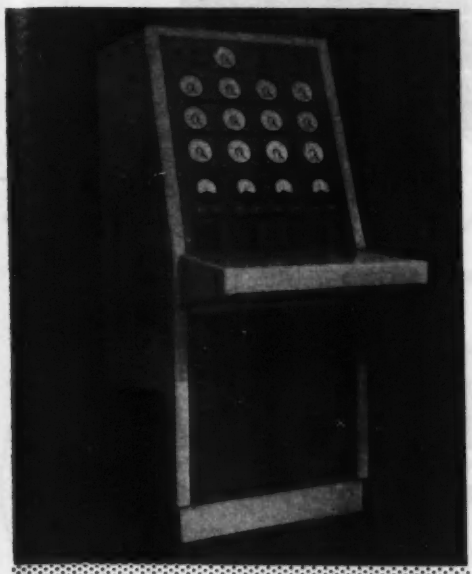

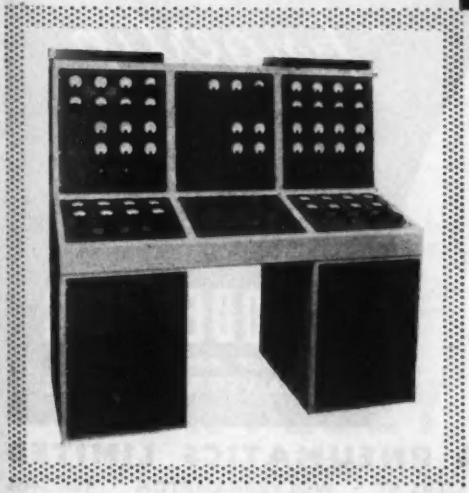

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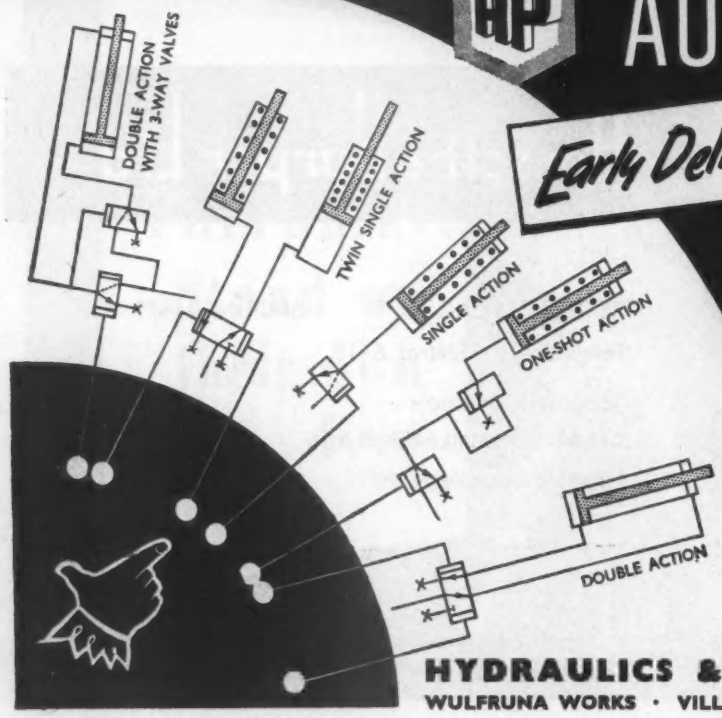

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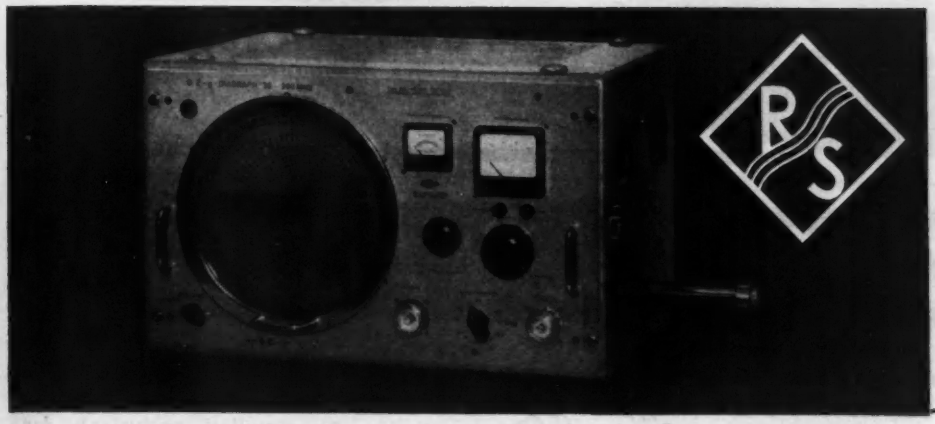

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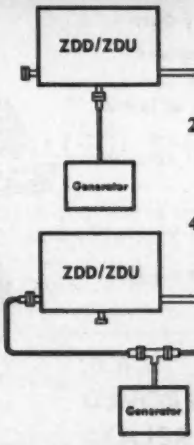

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The ideal tool for research and development, eliminating lengthy and difficult calculations in 2-terminal and 4-terminal networks.

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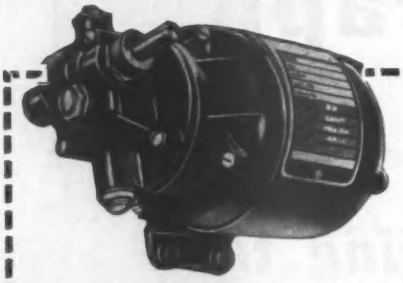

Output-shaft has 12 positions.

Integral Wormgear Reduction.

Ventilated — Drip Proof.

Vacuum Impregnated Windings.

Dynamically balanced Armatures and Rotors.

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R.P.M.	TORQUE	R.P.M.	TORQUE
600	10 oz. in.	37.5	4 lb.i n.
300	16 oz. in.	25	4 lb. in.
150	24 oz. in.	18.8	4 lb. in.
100	32 oz. in.	12.5	4 lb. in.
75	36 oz. in.	9.4	4 lb. in.
50	3 lb. in.	6.25	4 lb. in.

SHADED-POLE INDUCTION GEARED MOTOR—Type 'FA'

R.P.M.	TORQUE	R.P.M.	TORQUE
216	4 oz. in.	13.5	24 oz. in.
108	7 oz. in.	9	30 oz. in.
54	10 oz. in.	6.7	35 oz. in.
36	12 oz. in.	4.5	44 oz. in.
27	15 oz. in.	3.35	3 lb. in.
18	20 oz. in.	2.25	4 lb. in.

VARIABLE SPEED GEARED MOTOR—Type 'kQ'

R.P.M	TORQUE	R.P.M.	TORQUE
200-600	9 oz. in.	12-37.5	4 lb. in.
100-300	16 oz. in.	8-22	4 lb. in.
50-150	20 oz. in.	6-16.5	4 lb. in.
32-100	32 oz. in.	4-11	4 lb. in.
25- 75	40 oz. in.	3- 8.25	4 lb. in.
16- 50	48 oz. in.	2- 5.5	4 lb. in.

CAPACITOR INDUCTION GEARED MOTOR—Type 'N'

R.P.M.	TORQUE	R.P.M.	TORQUE
456	8 oz. in.	28.5	3 lb. in.
228	13 oz. in.	19	4 lb. in.
114	21 oz. in.	14.2	4 lb. in.
76	26 oz. in.	9.5	4 lb. in.
57	32 oz. in.	7.1	4 lb. in.
38	44 oz. in.	4.75	4 lb. in.

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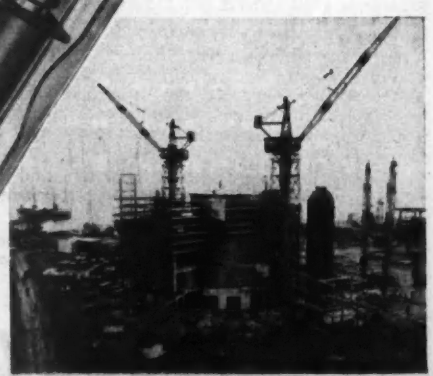

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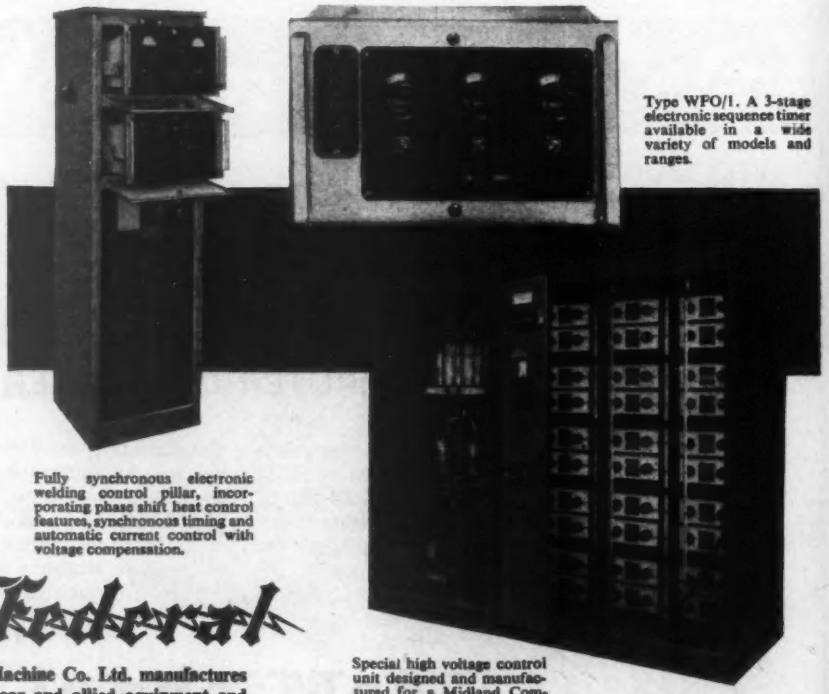

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TMC Elmeg Counters are as near perfect as they can be made by the human skills of technical experts with years of experience and the most advanced equipment at their disposal. As a range, they are exceptionally versatile—offering a choice which should match up to even the most remote requirements. Available in "Print-Out" and "Read-Out" form, they have fast operating speeds of up to 40 per second. They operate on up to 240 Volts, with uni-directional or bi-directional motions. Re-setting to zero by electrical, mechanical or electro-mechanical methods. There are auxiliary contacts operating on each revolution of a numbered wheel. The range includes counters for flush panel mounting and surface mounting. No special servicing is required.

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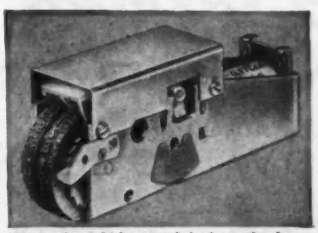
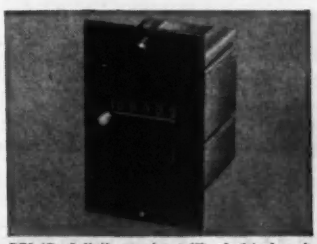


ZDmh—An 0-24 hours printout counter for vertical mounting.



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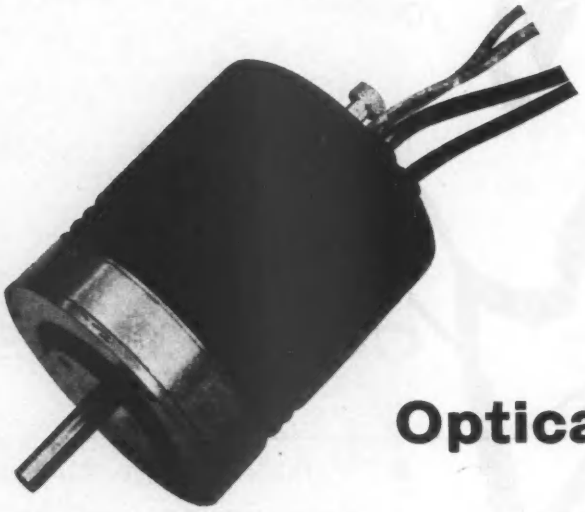

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- Only 3in. in diameter

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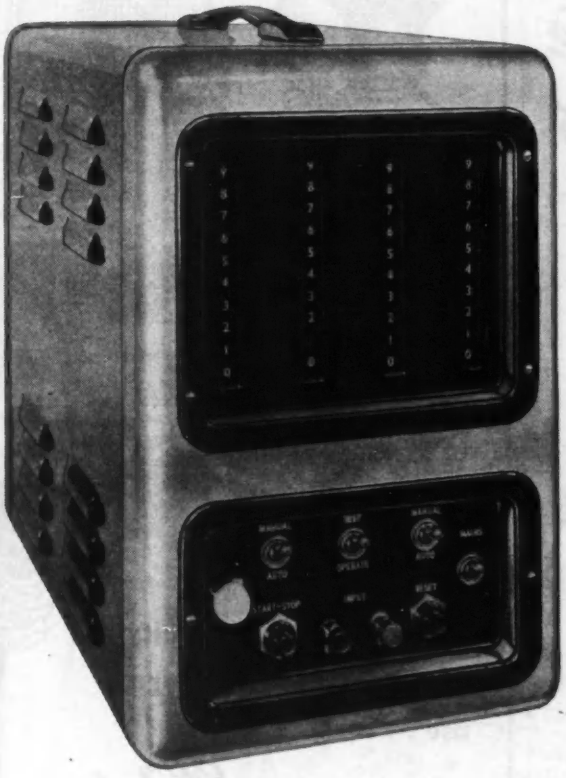

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£178 ex works, the cheapest 100 kc/s digital counter offering so many features

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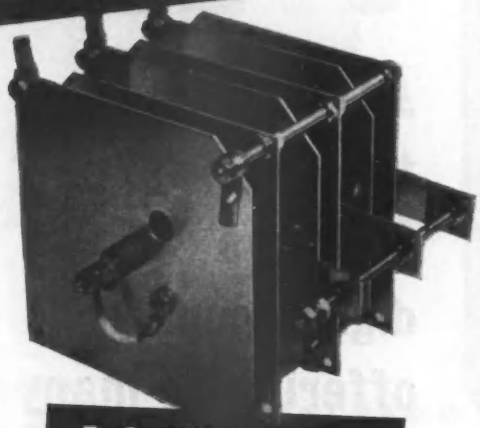

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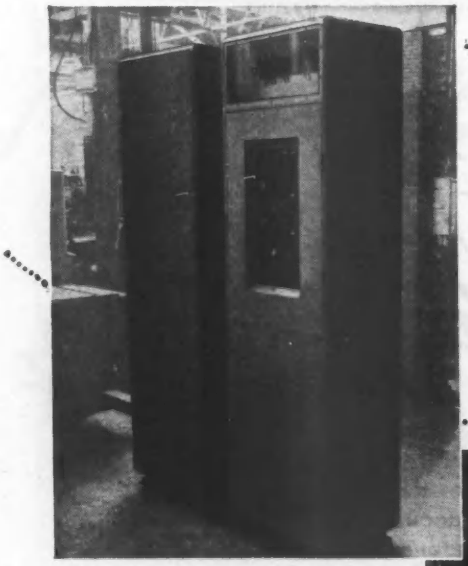

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a static switching system using Cold-Cathode Tubes, possesses the advantage of self indication.

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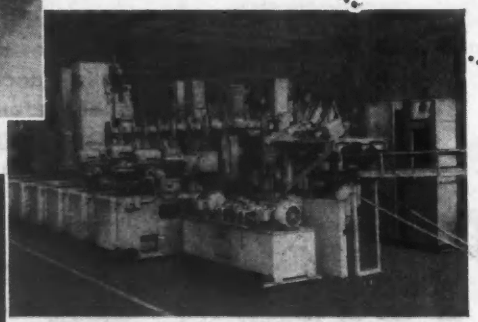

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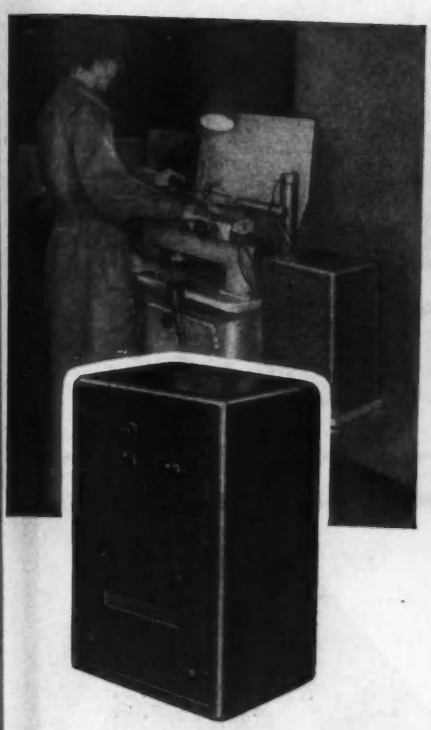

fixed programme controller
for simple applications.
Shown here as an operator's aid
on a commutator trimming lathe.

flexible programme controller
of great versatility.
Shown here applied to a Ward No. 2
capstan lathe for unattended operation.

The fixed programme controller using relay logic to control pneumatic cylinders has been found to give faster, easier working for the operator combined with increased safety.

The flexible programme controller uses cold cathode tubes for reliability. The programme matrix wiring is permanent and there are no loose external wires. Pneumatic and hydraulic (air-oil conversion) cylinders are used as appropriate.

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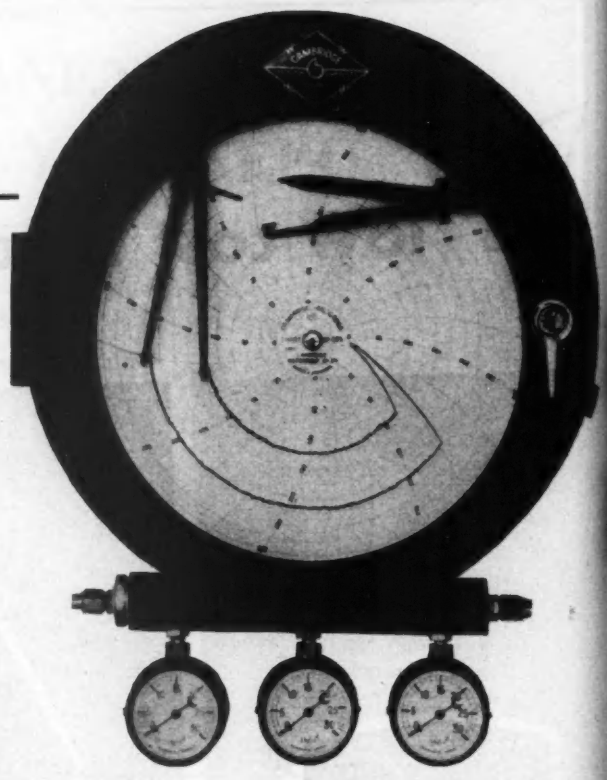

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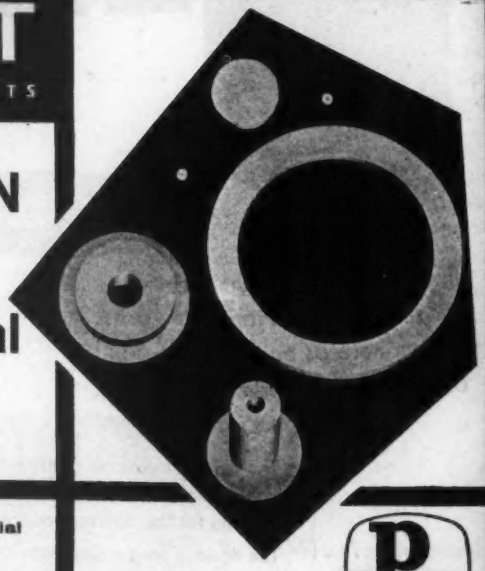

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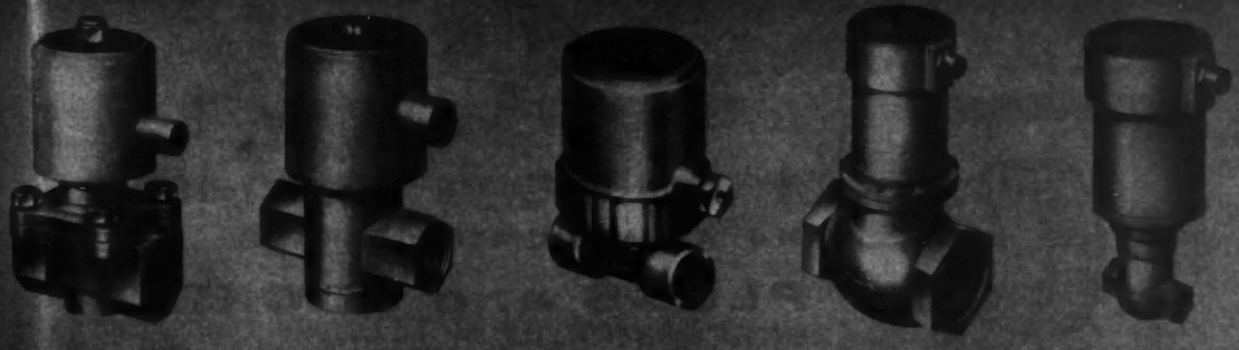

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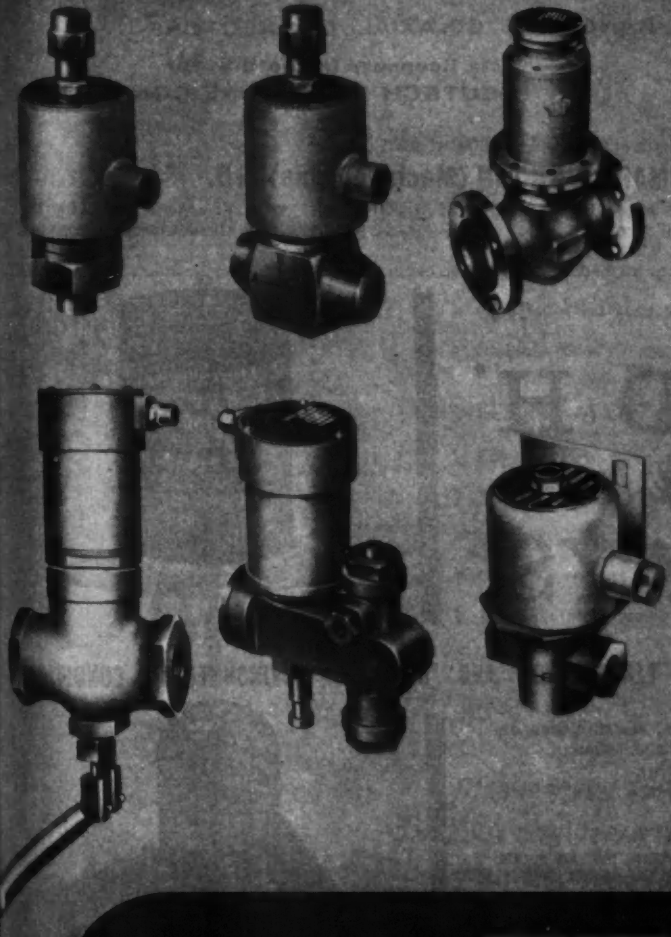

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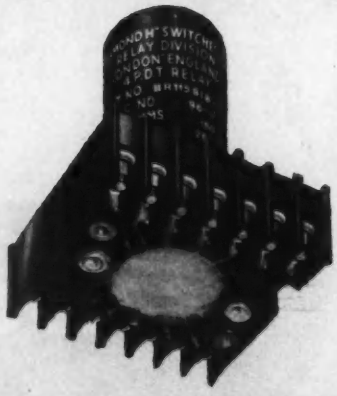

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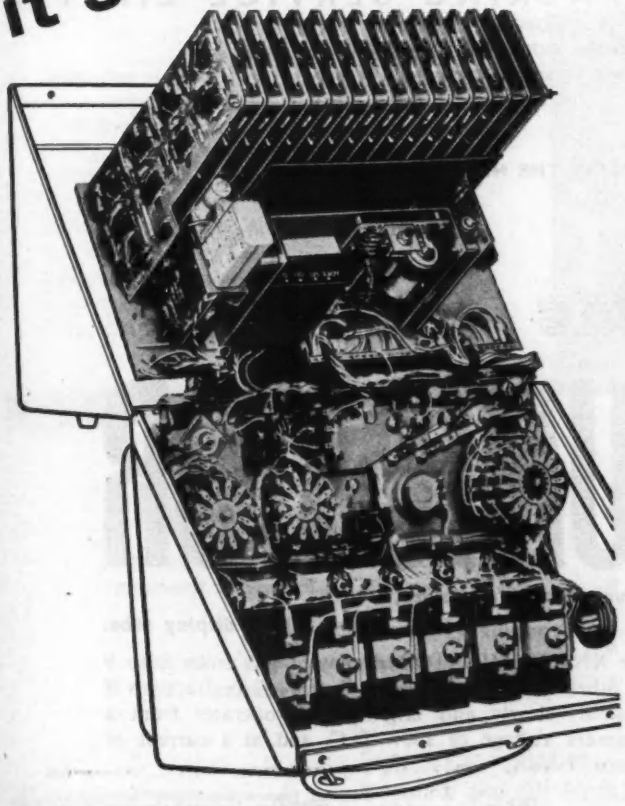
Advance TC1

1Mc/s TRANSISTORISED COUNTER

INTERKAMA STAND No. B/2025/6/D

it's the inside that counts



...in this case up to 1Mc/s. And the inside of the Advance time and frequency measuring counter type TC1 is rather exceptional. Over 145 transistors and 21 printed circuit boards have been combined in an advanced design to provide the full facilities and high performance expected of a first-grade laboratory instrument.

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★ **PERIOD MEASUREMENT** 1 or 10 periods of input waveform down to 10 c/s

RANDOM COUNTING totalling over any period

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FREQUENCY MEASURING PERIOD 0·1, 1·0 or 10·0 seconds

REPETITION OF COUNT manual or automatic

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DIMENSIONS length 12 in., height 9 in., depth 6 in., weight 12 lb.

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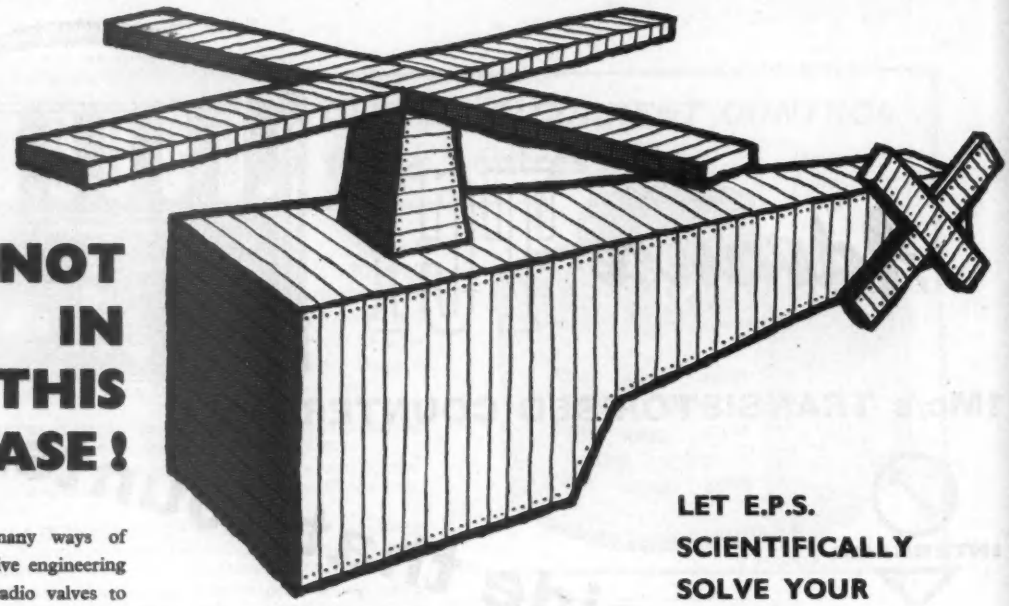

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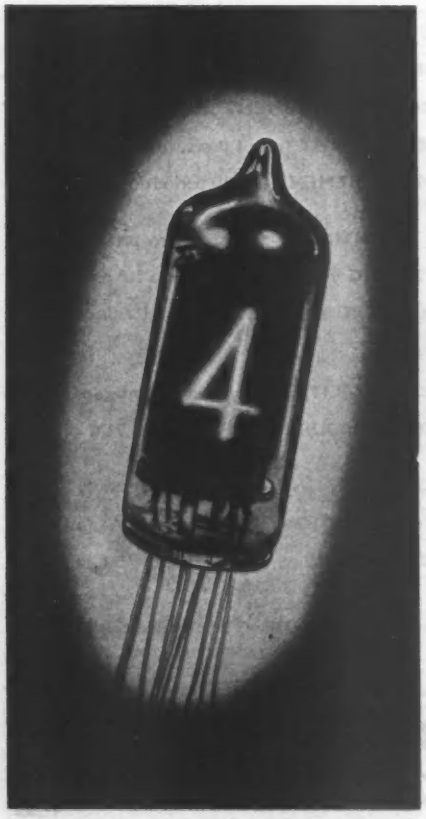

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a high quality miniature, in-line, digital display tube.

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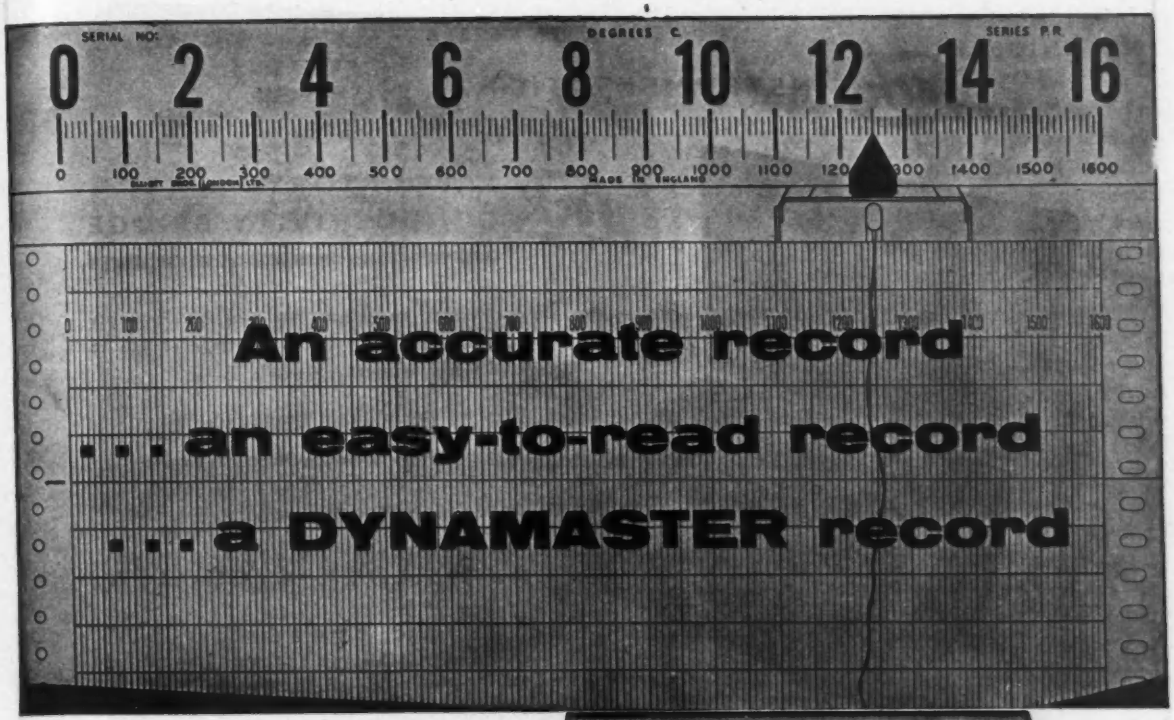
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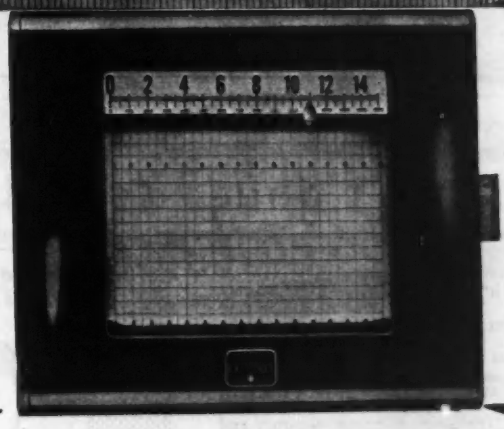

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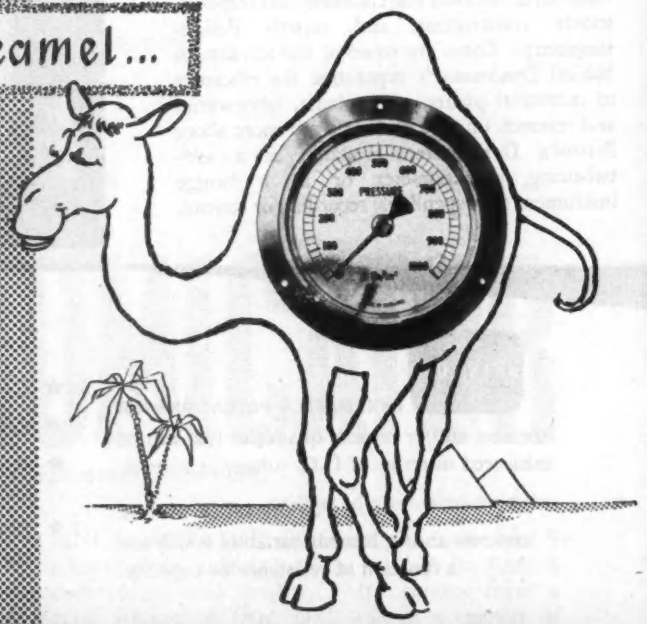

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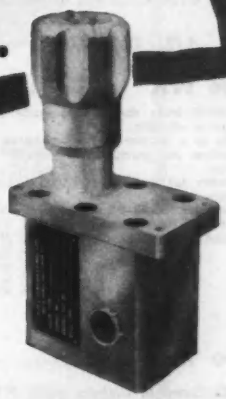

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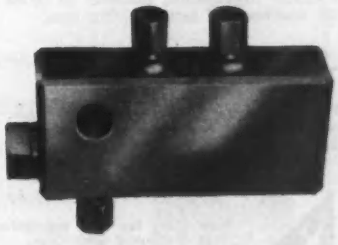

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Protects Gauges from sudden surges beyond their capacity. The adjusting screw is set to isolate at 90% of the gauge full scale reading. Fit a number of pressure gauges together with their appropriate isolators and obtain a very accurate indication of pressure throughout the entire system.

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Manufactured in highest grade P.V.C. in twenty-five different sizes from ¼" inside diameter to 2" inside diameter to cover the smallest and largest wiring runs.

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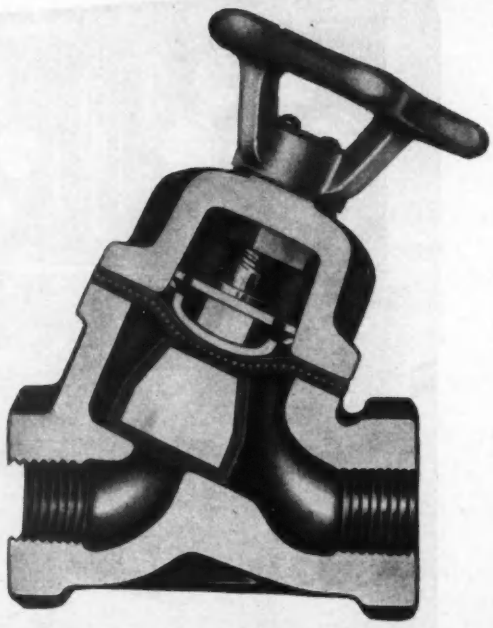

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D.D. diaphragm valves

Leak-proof control of Corrosives with positive shut-off

The diaphragm seals gas or fluid within the valve body while the disc ensures positive closure. Losses during operation are prevented and complete safety is ensured with corrosive fluids or gases. Oversize port design greatly increases the capacity of the valve.

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FOR ANALYSIS OF NOISE AND VIBRATION SIGNALS

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Many types of noise and vibration signals can be handled. Equipment performs automatic amplitude/frequency analysis of steady signals and automatic amplitude/frequency/time analyses of non-steady (time varying) signals.

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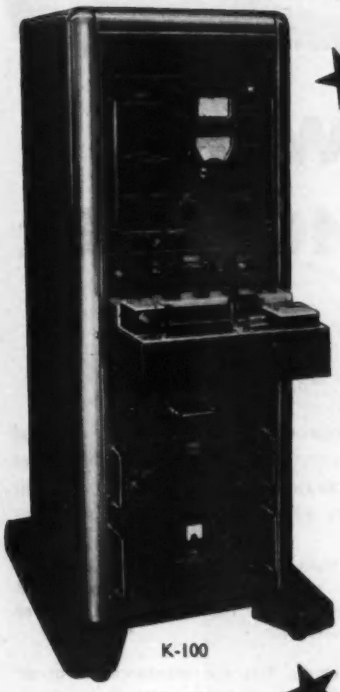
Equipment is fully automatic over entire range of 10c/s-19kc/s, but can be made to scan only part of the range.



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CHOICE OF THREE CONSTANT PERCENTAGE BANDWIDTHS

A choice of three bandwidths is available, ⅓ octave, 5% and 1.5%, giving octave discrimination of 30dB, 54dB and 70dB respectively.

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All results are presented on pre-printed amplitude/frequency calibrated or amplitude-calibrated papers.

FREQUENCY ACCURACY IS HIGH

Frequency accuracy of analyser alone is 0.5% and on output record, better than 1%.

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1mV-300V, dynamic range 44dB generally, or 300mV-300V, dynamic range up to 70dB with steady signals.

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At the end of frequency scan, analyser can be made to select new input signal with automatic chart advance—making multi-channel analysis very simple.

THE MUIRHEAD K-100 WILL SAVE TIME AND SKILLED MANPOWER

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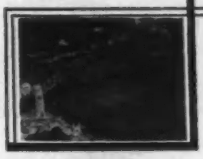

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TECHNIQUE

A Journal of Instrument Engineering for Scientists, Engineers, Technicians, Research Workers

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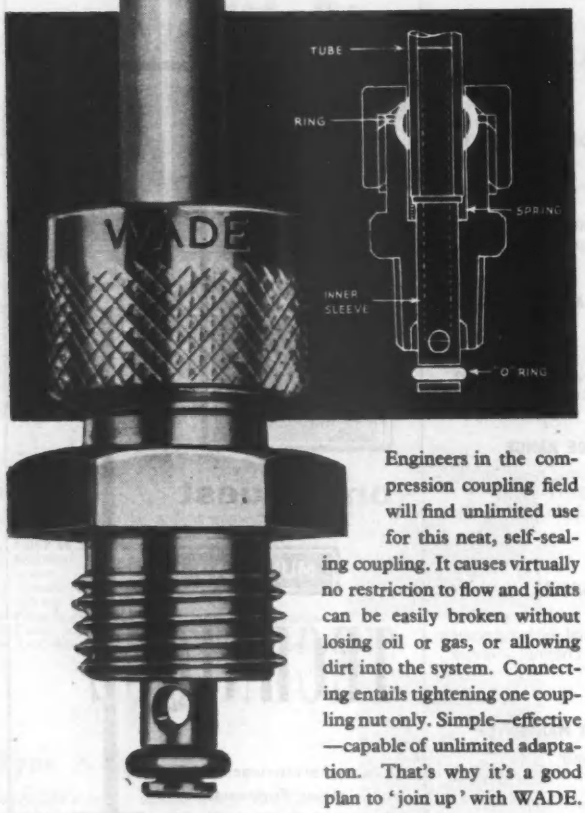
This Coupling is SELF-SEALING



Engineers in the compression coupling field will find unlimited use for this neat, self-sealing coupling. It causes virtually no restriction to flow and joints can be easily broken without losing oil or gas, or allowing dirt into the system. Connecting entails tightening one coupling nut only. Simple—effective—capable of unlimited adaptation. That's why it's a good plan to 'join up' with WADE.

WADE SELF SEAL Couplings are now available for $\frac{1}{4}$" and $\frac{5}{16}$" O.D. Tube × $\frac{1}{8}$" or $\frac{1}{4}$" B.S.P. or A.P.I. Also for Plastic Tubing $\frac{1}{4}$" O.D. × $\frac{5}{32}$" I.D. × $\frac{1}{8}$" or $\frac{1}{4}$" B.S.P. or A.P.I.

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WADE COUPLINGS LIMITED
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"PUSH BUTTON AND READ" THE THERMOMETER FOR YOU!

The SWEMA Thermometer TS 11 is an electrical quick-action thermometer with cross coil instrument for quick and accurate measurement. Can be connected to a variety of measuring probes such as:

PROBE MKT 12 for walls, windows, floors, radiators, pipes. The sensitive element is flexible and adopts entirely the shape of the object to be measured.

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Also available:
Displacement, pressure, and acceleration transducers

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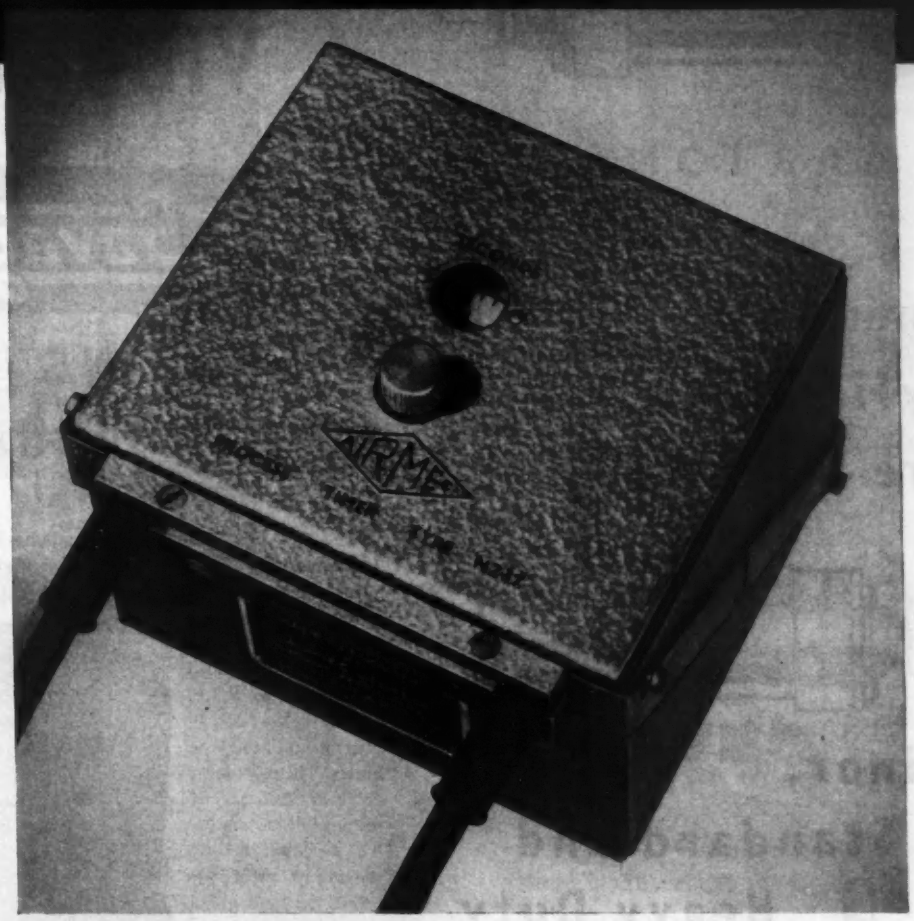

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PROCESS TIMER

The Airmec PROCESS TIMER Type N237 provides an accurately timed switching facility for industrial control purposes over the range 1-100 seconds.

It employs a mains operated single valve circuit which is largely self-compensating for variations in supply voltage. Switching is effected by an output relay fitted with both heavy- and light-duty changeover contacts which are independent of the starting signal circuit.

- **No electrolytic capacitors.**
- **No moving parts to wear out.**
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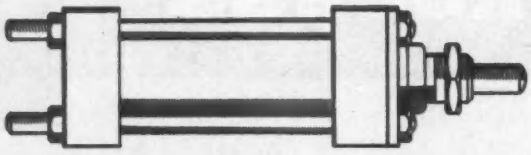

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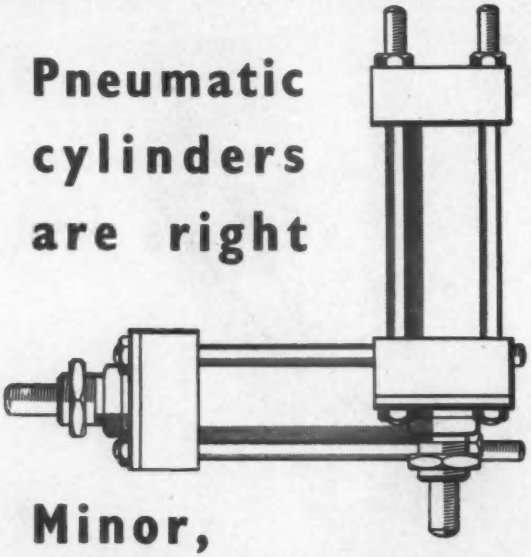

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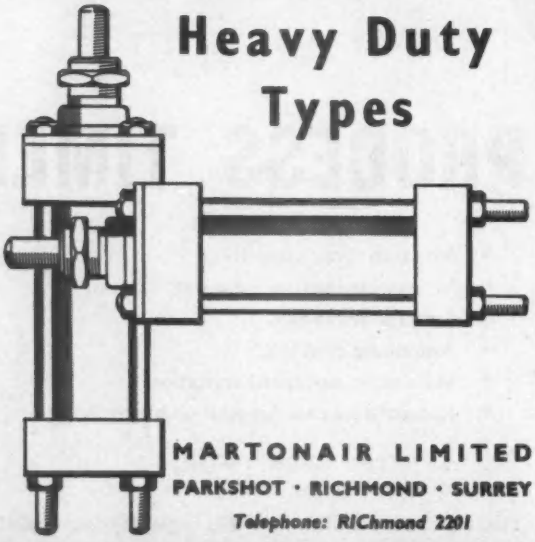

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W. BRYAN Savage

MOVING COIL VIBRATOR

TYPE V1000C

This vibrator has been developed to fill in the need for a medium power vibrator with a table surface in place of the usual single point drive spigot. The table is cast from a high duty magnesium and is 6 in. (15.2 cms.) in diameter and provided with 12 × ¼ in. B.S.F. tapped holes for attachment of the test object. The moving coil is attached directly to the table casting. The weight of the moving system is 17.6 lbs. (8 kgs.) and a bare table acceleration of 31 "G" peak can be obtained for an input current of 10 amps., which is equal to a thrust of 550 lbs. peak for an input power of 1 kW. The vibrator can also be supplied with a blower (V.1000C.B.) and will deliver a thrust of 750 lbs. peak for an input power of 2 kW. Can be trunnion mounted if required.

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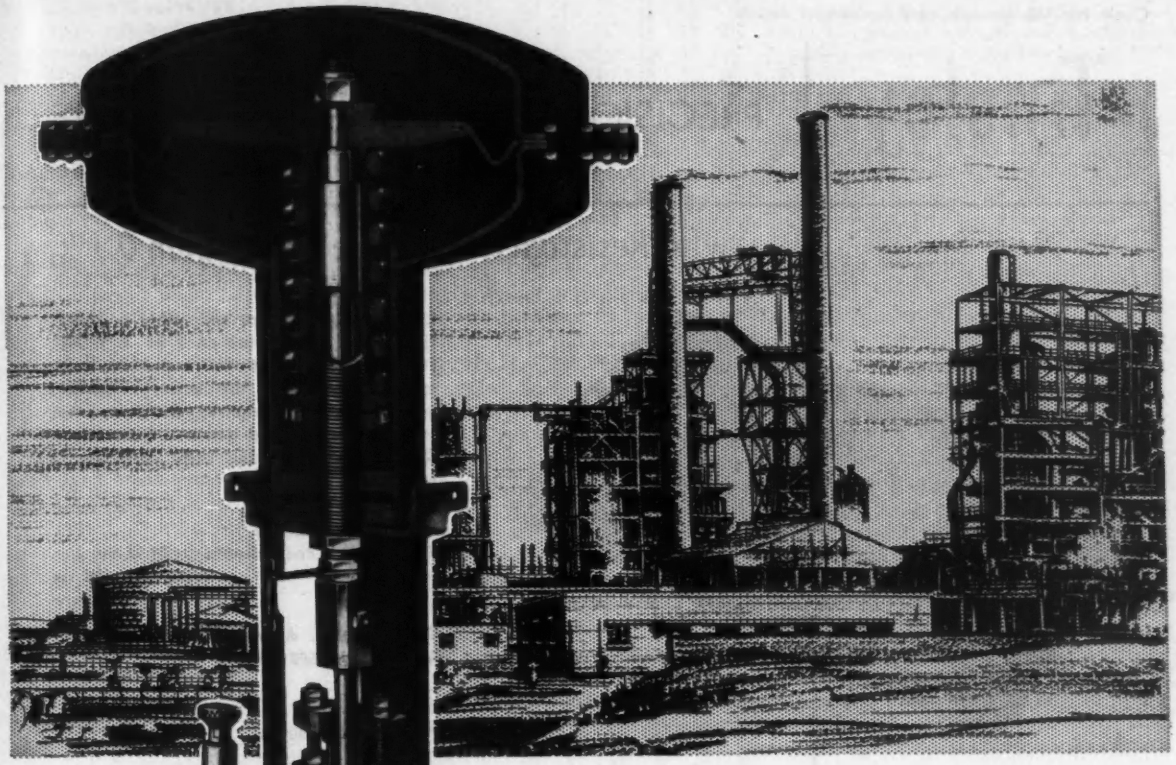

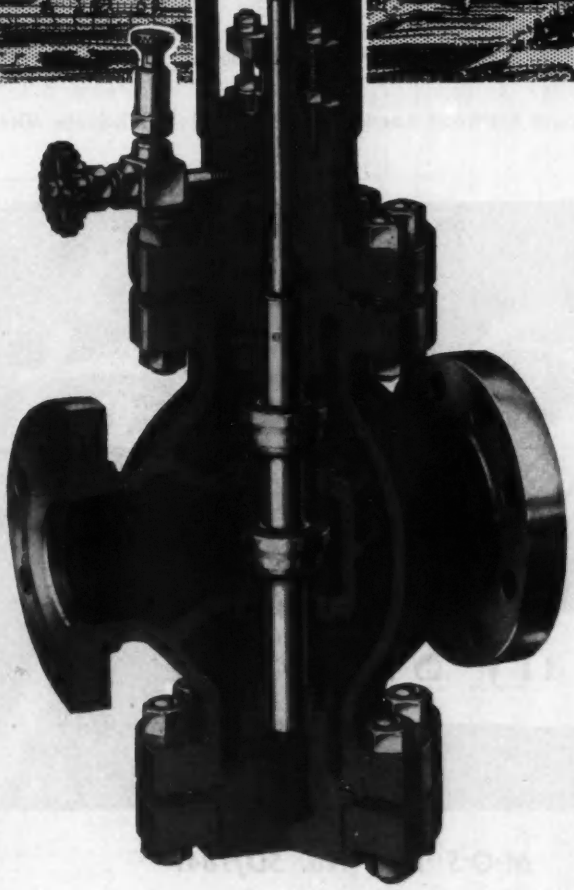

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BLAKEBOROUGH

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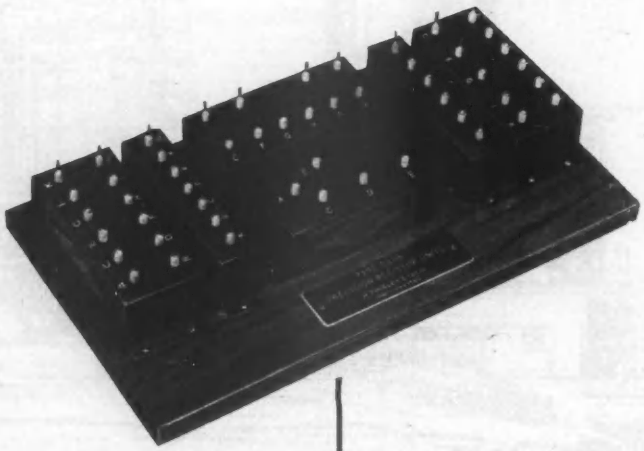
Tinsley

PRECISION COMPONENT RESISTORS

with Resistance tolerance better than 0.1%



Exceptionally compact and light in weight the Type 5206 resistor units of *very high stability* are hermetically sealed in metal cases. Designed for use where resistances up to 10 MΩ are required, the units meet the specifications laid down in R.A.E. Spec. G.1177 and satisfy the tests described in Spec. R.C.S. 11.

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Temperature coefficient : ± 20 parts per million per °C at room temperature

Time constant: Approximately 10^{-4} seconds
Max voltage: 500 V d.c.

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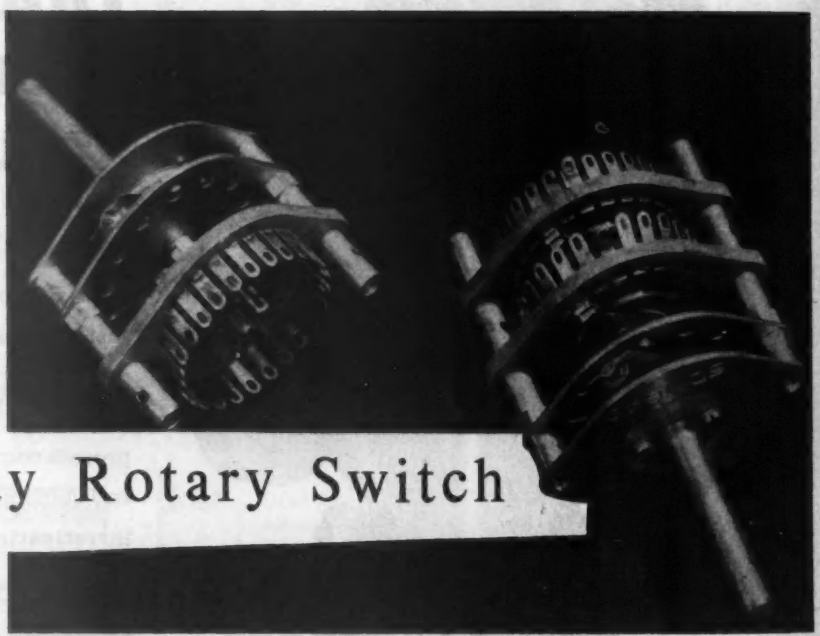

A total of 156 ways per switch are possible

26-way Rotary Switch

Hendrey Relays

M·O·S Type No. 5D/1849

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CONTROL READER INFORMATION SERVICE September 1960

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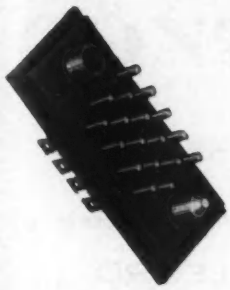

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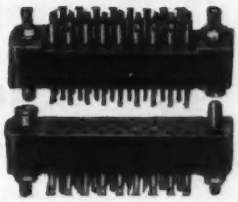

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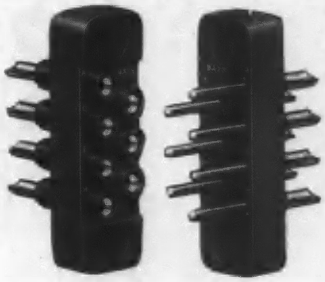

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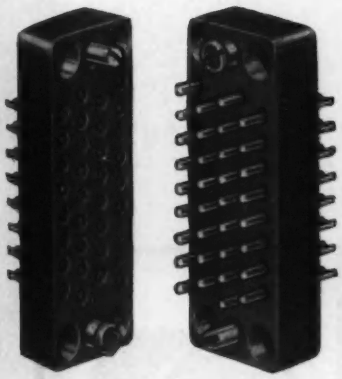

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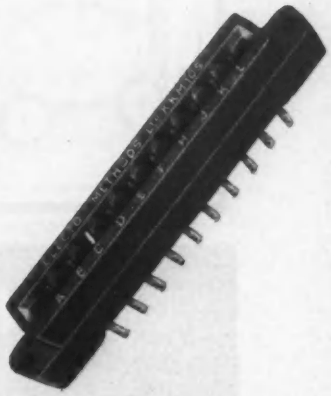

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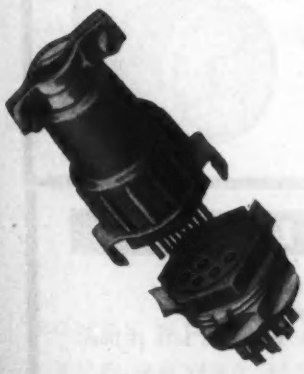

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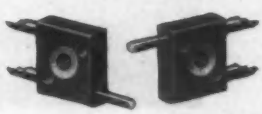

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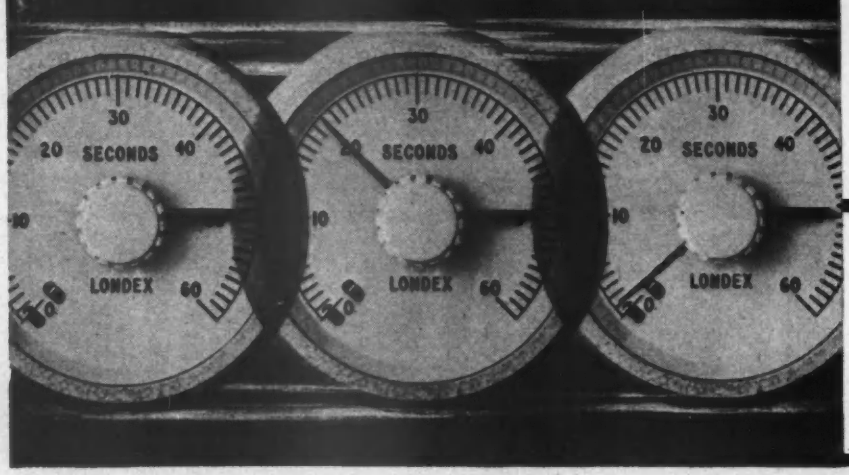

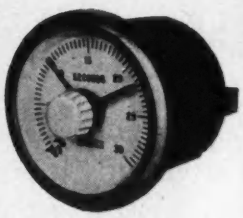

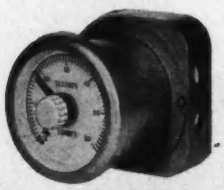

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CONTROL

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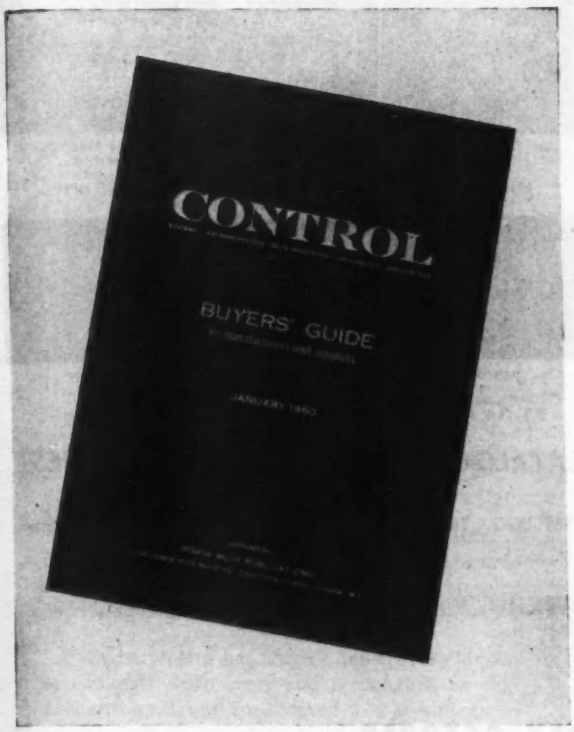

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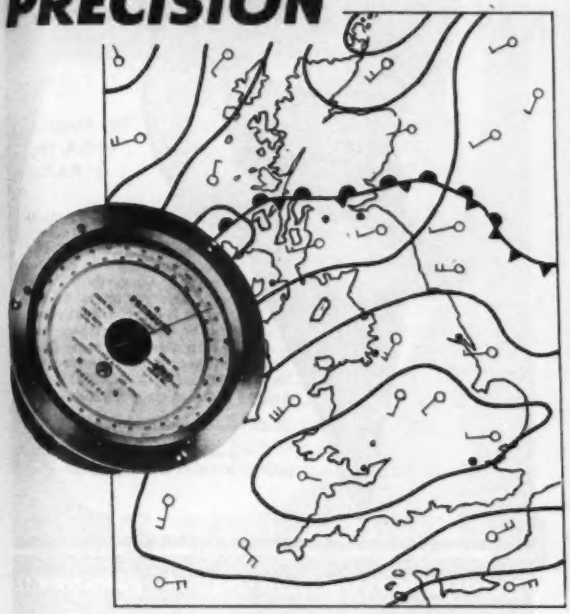

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Range:	100 mbs., 75 mm. of mercury or 3 in. of mercury for any selected station pressure
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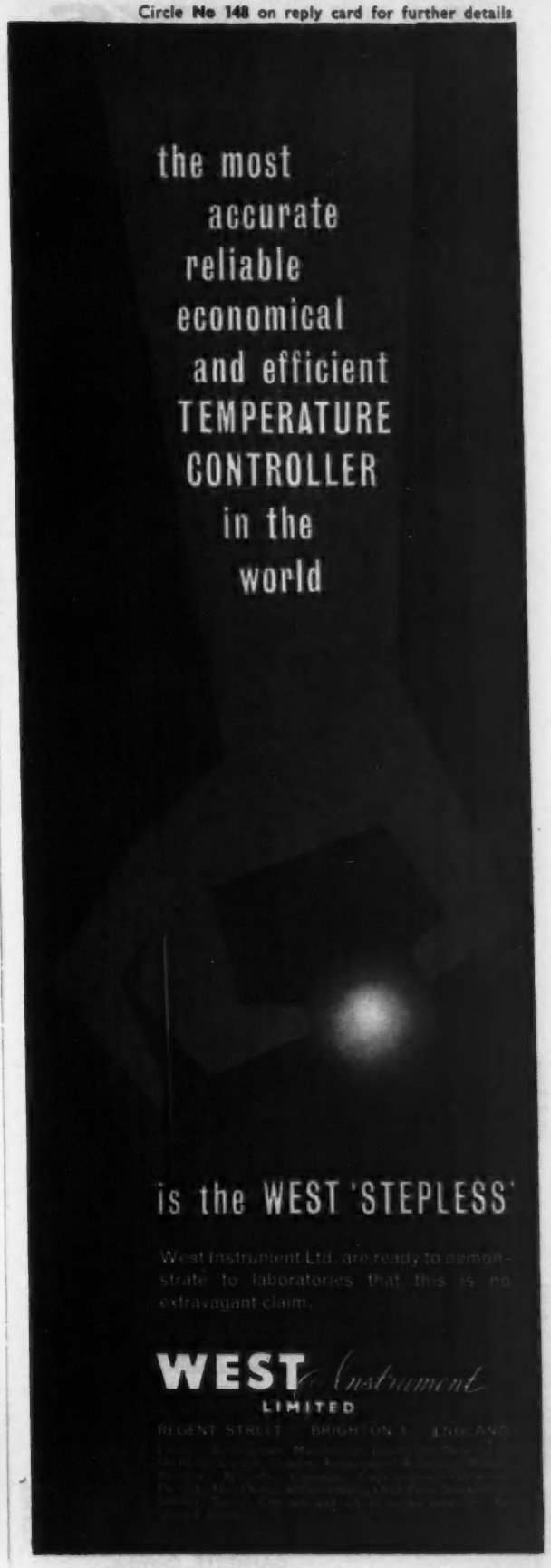

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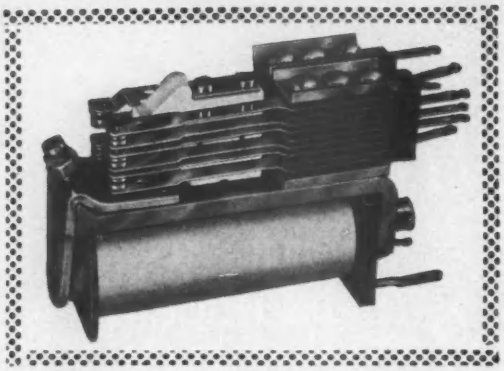
TO SPECIFICATION



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Large Gapmeters are made for ¼", ¾" and 1" B.S.P. sizes (nozzles or compression unions).

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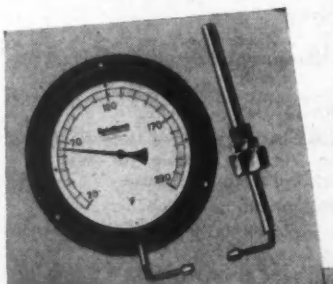

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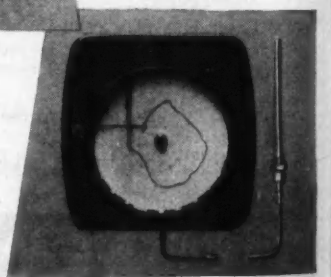

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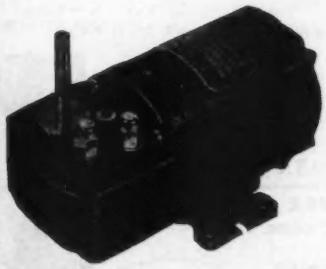

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- ★ Cuts wiring time by 52%
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- ★ Proof of the way Cradleclip saves time and money is available in our Time and Motion Study Report which will be sent to you on request.

. . . that's cradleclip

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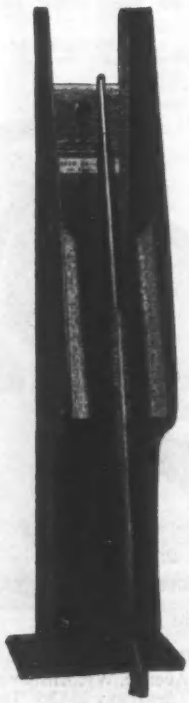

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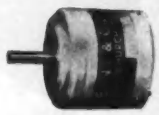

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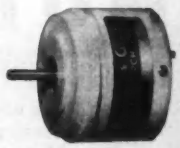

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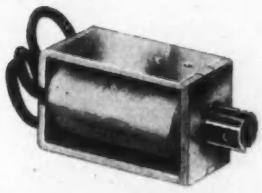

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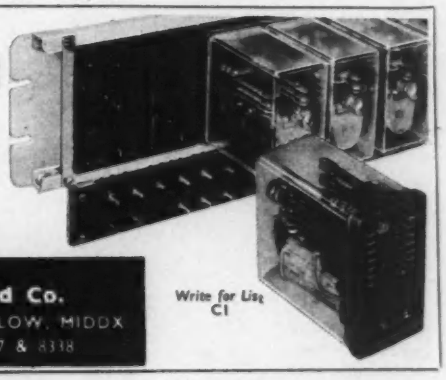

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